Assessment of Noise Effects on Sensitive Animal Communities

Thesis

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Thesis

of

Michael Roger Forsdyke

BSc Zoology – University of London
MSc Environmental Pollution Sciences – Brunel University
Diploma of the Institute of Acoustics
Member of the Institute of Acoustics

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ABSTRACT

There is a statutory requirement to protect certain animals and to assess the environmental effects of new developments on wildlife. However, there is no formal guidance on how such assessments should be undertaken. This research has developed an assessment process specific to animals, which enables informed judgement as to the likely short or long-term impacts. Published animal responses have been analysed to identify particular trends and response thresholds, and a standard procedure for assessing noise effects on animals has been developed. The procedure assigns significance criteria (no effect, slight, moderate and severe) that take account of the physiological and behavioural responses exhibited following exposure to noise. The significance rating determines whether mitigation is required.

Particular combinations of noise, animals and habitat that are especially sensitive to environmental noise are identified as off-road vehicles, helicopters, very quiet habitats, and animals having special hearing characteristics.

An assessment threshold is proposed based on key factors such as the noise level, source distance, and other site-specific circumstances. If L_{Amax} noise levels are greater than 80 dB or the separation between the animals and the noise source is less than 1,000m, an assessment is recommended. For fish and marine mammals, if the Received Level (RL) is greater than 140 dB re: 1μPa rms an assessment is recommended. Slight responses may still arise below these thresholds but moderate or severe responses would not be expected. Circumstances most likely to affect animal responses are a rapid onset of noise, and the presence of helicopters, sonic booms, low flying aircraft, artillery/rockets, blasting/explosions, fireworks, motorboats or float planes.

The assessment methodology is tested on two animal species (black grouse and golden plover) using data from a planning application for military development, and retrospectively to mammals at a wildlife park where low-flying jets had caused moderate/severe responses.

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FIGURES (in text)

APPENDICES

1. INTRODUCTION

1.1 Legislation

Existing and proposed developments, such as highways, railways, airports, retail parks and commercial/industrial developments, invariably generate noise, and often airborne or ground-borne vibration, to varying extents during their construction and operation. The routine assessment of the impacts of such developments on humans and the environment in general was first brought under EC laws through Directive 85/337/EEC[1] (Directive on assessment of effects of certain public and private projects on environment). The requirements of this Directive were incorporated within UK legislation through the Town and Country Planning (Assessment of Environmental Effects) Regulations 1988[2]. In March 1999 the above Directive was updated by Directive 97/11/EEC[3] and, in turn, the various UK Statutes under the Town and Country Planning Act were revoked and re-enacted by the Town and Country Planning (Environmental Impact Assessment) Regulations 1999[4].

The regulations identify development that is 'EIA Development', i.e. which requires an Environmental Impact Assessment, and defines these as either Schedule 1 or Schedule 2 developments. Schedule 1 represents the major developments, other than exempt development such as national defence projects or projects exempted by the Secretary of State, for which an EIA would routinely be required as part of the planning application process. Schedule 2 development is likely to have significant effects on the environment by virtue of factors such as its nature, size or location. Definitions of Schedule 1 and 2 developments are repeated here in Appendix I.

All development in Schedule 1 of the Regulations requires an EIA. For development in Schedule 2, that which is either to be carried out in a sensitive area or satisfies a threshold or criterion relating to its size requires an EIA if it is likely to have significant effects on the environment. The local planning authority or the Secretary of State can provide a 'screening opinion' or 'screening direction' respectively as to whether Schedule 2 development is to be treated as development requiring an EIA. The same authorities can provide opinions or directions regarding the scope of information to be included in the environmental assessment.

With regard to 'sensitive areas', the Regulations refer to land and sites regulated by the following laws and bodies:

- the Wildlife and Countryside Act 1981 (amended 1985);
- the National Parks and Access to the Countryside Act 1949;
- the World Heritage List under article 11(2) of the 1972 UNESCO Convention for the Protection of the World Cultural and Natural Heritage; and
- the Conservation (Natural Habitats etc.) Regulations 1994.

Noise forms one of several topics routinely required by the EIA, which should cover a "*description of the aspects of the environment likely to be significantly affected by the development, including, in particular, population, fauna, flora, soil, water, air, climate factors, material assets, including the architectural and archaeological heritage, landscape and the inter-relationship between the above factors*". No specific definition is given to the term 'fauna', or to the other aspects of study, however, a dictionary definition of 'fauna' is "all the animal life of a given place or time".

Within the UK, further guidance on environmental assessment specific to new road construction can be found within the Department of Environment, Transport and Regions (DETR) 'Design Manual for Roads and Bridges' (DMRB)[5]. Amongst other matters, the DMRB provides guidance on Ecology and Conservation, describing each respectively as the "study of living organisms and their relationship both with each other and the non-living environment" and nature conservation being concerned with "maintaining a viable population of the country's characteristic fauna and flora and the communities they comprise". A consultation draft on 'Guidelines for Noise and Vibration Impact Assessment'[6], prepared jointly by the Institute of Environmental Management & Assessment and the Institute of Acoustics and due for publication late 2004, likewise identifies the need for an EIA to cover the impacts on wildlife and other animals where necessary.

One of the screening criteria proposed by the US Environmental Protection Agency (EPA) is the degree to which an action disrupts stable ecosystems, especially when an endangered species is involved[7]. In the US, section 7 of the Endangered Species Act requires federal agencies to ensure that any action authorised, funded or carried out by them is not likely to jeopardise the continued existence of listed species or modify their critical habitat[8]. Section 7 of the Act also requires agencies to prepare a biological assessment if the U.S. Fish and Wildlife Service (USFWS) has advised that an endangered or threatened species is present in the area targeted for development. The assessment should describe impacts on animals at both individual and population levels, and should consider physiological and behavioural effects and the consequences of those effects on species demography.

1.2 Animal Populations

The term 'viable population' represents an important factor in this research since although noise, and/or vibration, might have an adverse and perhaps lethal effect on individual animals (for example those weakened or susceptible through ill-health, disease, age or other factors) provided the population as a whole remains relatively stable within the area of interest then no adverse impacts to that species will arise. In some cases, therefore, it will be necessary to distinguish between effects that can be adverse for individuals only and those that can be adverse for the entire species. However, the distinction will not always be that simple; for example, where the individuals have large territorial areas, which tends to result in large separation distances between 'neighbours', the loss of just a few individuals will take on a greater significance, either in terms of conservation value as discussed below or with regard to finding mates.

The DMRB explains that "Conservation of wildlife species and their habitats is important both for inspiration and enjoyment and to sustain the value of the natural environment as an asset for recreation, education and direct economic benefit". In the above example where the population is spread thinly, although adverse harm to the individual animals within an area of concern might not adversely affect the overall population within the region or country, it nevertheless would adversely affect the values identified above by the DMRB. In contrast, where animals live within large communities, such as bird colonies, adverse impacts on some individuals, which nevertheless do not alter the viability of the group as a whole, are likely to be tolerated in the same way that natural factors such as predation and disease pick off the weaker individuals within a species.

The above comparison between effects on individuals and species is further complicated by the need to consider population sizes over periods longer than one year, and the need for accurate understanding of the implications of changes to population numbers. Although some adverse effects can be immediate, others that influence factors such as courtship, reproduction, nesting and feeding/predation etc. might only materialise over time as population numbers steadily decline in the presence of a persistent or intermittent cause. This highlights the difficulty in determining adverse effects based on only short-term data, and the need for long-term studies, which are typically beyond the ability of the EIA. A condition of planning permission might be to undertake population studies for a period after development, however, this presupposes that some mitigation of adverse effects is possible after the event. For certain sources, e.g. military uses or new development in an area previously unaffected by noise, the opportunity to apply further noise controls might not be available.

The correct analysis of changes to population numbers is also important. Where a long-standing viable population is present and the numbers decline after introduction of new development, it can generally be accepted that the development has had some adverse impact on the animal community. The change may not be unacceptable to the community if it (the community) has simply relocated to an equally satisfactory home range remote from the new development, and at the same time does not produce adverse effects on other animal species, flora or landscape etc. in the new home range. Such a relocation, nevertheless, could be seen to have an adverse effect on the conservation value of the vacated site, especially if it upsets the balance between remaining fauna and flora.

In contrast, increasing population numbers following new development might be viewed as no impact or even a beneficial effect, since the species has to all intents and purposes been able to thrive. Yet the change in population numbers might hide an underlying problem, which could lead to other and more damaging consequences over time. For example, where an animal uses sounds to establish its presence and hence its territory, an increase in ambient noise levels might interfere and mask the audibility of such vocalisations to the extent that individual territories decrease in size. The end result will be an increase in territory numbers and hence an increase in population numbers, which might be perceived as beneficial. However, increased numbers will tend to lead to increased competition for mates, especially where the territory is determined by the male of the species. There will in turn be increased fighting between competing males, and increased competition for nesting sites and food, all of which will have an effect on the longer-term stability of the population within that area. Similar but indirect effects can arise and be equally important if noise impacts upon predators to the extent that behavioural changes or a decline in numbers allows a growth in the local population of their prey.

An assessment of the stability of a population effectively requires information on recent population trends for comparison with any changes that might take place after development. A number of methods are available for estimating population numbers[9] but unfortunately most EIAs do not allow sufficient time or resources for such studies. Some background information might be available from Government bodies such as English Nature or from local Natural History Societies, or relevant organisations such as, in the case of birds, the British Trust for Ornithology or the Royal Society for the Protection of Birds. However, even if information is available for a given locality it still needs to be properly analysed.

The analysis of biological populations typically means an analysis of why a population is as large as it is and what factors cause it to change. Therefore, to correctly identify the effect that extraneous factors such as noise might have on a population it is also necessary to establish the extent and nature of natural variations that might ordinarily take place in a population[10]. The simplest population will involve a single species in one place that does not interact with other species, but such a situation will be rare in nature. In most cases the area of concern will comprise quite complex systems made up of mixed species populations that interact not only with each other but possibly also via the flora within their habitat.

Most populations tend to show some irregular variation from one year to another[10], for example breeding populations of the great tit have been observed to exhibit variations of up to five-fold changes during a period of thirty years. Similarly, in addition to the year to year variations, there can also be significant variations throughout a year most particularly associated with seasonal variations. In a few species, e.g. lynx, ptarmigan and larch bud moth, there exists a strong cyclical variation in population numbers, which will often be linked to some physical cyclical event such as sunspot cycles.

The main difficulty in analysing changes in population size will be to firstly define what the normal mean population would be after taking account of the irregular or regular variations that normally affect the species, and secondly, what normally causes the variation and to what extent emissions of noise might alter this cycle. For most populations, numbers are limited in a density dependent way, i.e. they tend to decrease when high and increase when low thereby maintaining a stable population. In fact there are only four factors that can change the size of a population and these are births, deaths, immigration and emigration. Physical conditions that can in turn affect the above four factors can be summarised as follows:

- weather;
- enemies - predators, parasites, disease etc.;
- food and other similar requirements of the animal; and
- self limiting systems such as the territorial behavioural characteristics of birds.

An assessment of noise will need to consider how a new noise source might interact with the above physical conditions, and what will be the consequent effect on the four principal factors of births, deaths, immigration and emigration. If a new development has the potential to alter the natural rate of variation between annual population numbers, especially if numbers at the low or high end fall below or rise above what is a viable population taking account of local circumstances such as territory and food, then such effects will need to be identified and appropriate controls or mitigation implemented.

Finally in analysing population numbers, it will also be necessary to take account of periods of the year when population numbers will naturally vary due to factors such as hibernation and migration or other climatic, seasonal or locational variations. Regard will also need to be paid to those animals and their habitats that have statutory protection, especially at certain times of the year such as during breeding and hibernation. General guidance on breeding and overwintering periods for some important species within the UK is shown in Appendix II.

1.3 Statutory Protection

The DMRB guidance is also useful in that it supplements the legislation referenced in the Town and Country Planning Act with the following references or organisations that equally have some relevance with respect to the conservation of wildlife:

- the Countryside Act 1968;
- the Environmental Protection Act 1990;
- the Badgers Act 1992;
- EC Directive 79/409/EEC 'Conservation of Wild Birds';
- EC Directive 92/43/EEC 'Conservation of Natural Habitats of Wild Fauna and Flora';
- UNESCO 'Man and the Biosphere Programme' Biosphere Reserves - to conserve, for present and future use, the diversity and integrity of communities of plants and animals within natural ecosystems, and to safeguard the genetic diversity of species;
- Council of Europe's Biogenetic Reserves - to secure long-term conservation of a representative sample of biotopes (habitat types) of a European significance;
- Ramsar Convention Ramsar Sites - to conserve Wetlands of International Importance especially as waterfowl habitat;
- the 'Berne' Council of Europe Convention on the Conservation of European Wildlife and Natural Habitats - covers the protection of mammals, birds, amphibians, reptiles, freshwater fish, invertebrates and plants; and

- the Bonn Convention on the Conservation of Migratory Species of Wild Animals.

A number of wild animals within the UK enjoy varying degrees of protection under legislation such as Schedule 5 of the Wildlife and Countryside Act, 1981 as amended and revised in 1985 and 1991 and the Wildlife and Countryside (Amendment) Regulations 1995, and, in the case of birds, Schedule 1 of the Act and EC Directive 79/409/EEC. The protected animals include some mammals, reptiles, fish, amphibians, birds, butterflies, snails, beetles, moths, spiders and various other insects and marine life. Lists of the species protected within the UK are presented in Appendix III and are subject to change.

It is evident from the various legislative documents and guidelines referred to above that there is a legal requirement to consider the noise impacts of new development upon animals, and that some animals are specifically protected by law. An environmental assessment, however, should not be limited to just those animals protected by law. Likewise, this research does not limit itself to just those animals within the UK or Europe but to as many species as possible in order to build up as comprehensive a picture as possible regarding the potential effects of noise on individual animals and animal communities. For any environmental assessment it will be necessary to identify those animals within the local population of animal species that are actually susceptible to changes in noise exposure so that the resources focus on animals that are actually at risk. For example, not all animals use or respond to sounds within the environment; some do not produce any form of vocalisation, e.g. the newt, and do not possess auditory sense organs. As a consequence they may not be as sensitive to changes in noise within their environment.

Even in the absence of organs capable of responding directly to air pressure changes some animals still remain sensitive to vibrations, both airborne and groundborne. In some cases this is limited to direct 'touch' upon the skin but in many animals there is a response to vibrations within the medium around them whether it be in air, water or land. Therefore, in reviewing the effects of noise on animals, this research also considers the effects of vibration. As for noise, the EIA process will need to screen out those animals that are not sensitive to vibrations. The newt responds to water pressure changes in its immediate vicinity caused by the flicking of the tail towards its prospective mate during courtship, however, it is unlikely that normal levels of environmental vibration would interfere with this behaviour or cause harm to the animal's ability to respond to such localised movements. At the other extreme, however, shock waves such as from ground or underwater blasting would produce much larger pressure changes that could have serious effects, such as concussion or death, which should not be ignored.

1.4 How do animals use sounds?

Generally speaking, those animals that can generate sounds, e.g. for communication purposes, use complementary organs for hearing sounds else their vocalisations would serve no purpose. In some instances, noise may be generated purely as a by-product of a physical/mechanical process such as the buzzing produced by a bee's wing movements during flight. Although the noise is audible to ourselves and other animals, it serves no sensory purpose for the bee. However, although in many cases the inability of an animal to vocalise may reflect that species' inability to hear and respond to noises, this will not always be the case. Others will be able to respond to ground-borne noise or vibrations, or air pressure waves, which stimulate sensory cells within the skin or within limb extremities that are in contact with the ground or medium carrying the pressure changes.

The main advantage of being able to respond to sound is that sounds carry information that can be of vital importance to an animal's survival and well-being. Sounds provide a means of communication between individuals, which are important during courtship and also as warnings. Likewise, the detection of sounds from prey is important during feeding, just as the detection of sounds from a predator may help the prey survive. Once a sound has stimulated the appropriate sense organ it will, subject to factors such as its intensity, frequency content and duration, trigger appropriate reactions and behavioural responses within the listener. An animal that can respond to sounds has the added advantage that it can learn to respond to sounds produced by other species, for example bird warning calls will often elicit responses from individuals of another bird species.

Although sounds often tend to elicit responses that may be immediately noticeable to an observer, for example they may cause an animal to be startled and respond by 'flight' - i.e. rapid movement away from the source of the noise, the most important responses may not be perceptible to an outsider. In many cases of sound generation and detection, the sound will facilitate physiological adjustments of the body to cope with impending demanding situations. In the wild there exists a continual and natural prey/predator relationship between carnivorous species, and in this context sounds will often be used to signal danger. For survival, it is important that the body makes reflex adjustments to cope with any threat, and these adjustments will include the redistribution of blood (e.g. to supply oxygen to areas where there is likely to be a high energy demand - such as hind limbs or wing muscles) a rise in systemic blood pressure, and general increase in muscle tone.

Modern society and its associated infrastructure and developments contain numerous and varied noise sources that, like the biological noises, can generate similar responses within species that have the ability to detect and respond to them. Such noises may not themselves pose a direct threat to animals but they can nevertheless induce physiological adjustments, such as those described above, that may result in unnecessary or inappropriate responses in the affected animal. If such responses are persistent or extreme they may subsequently affect an animal's health or increase the risk of death. It is therefore important to be able to quantify the risks to different species or individuals within a species, and where possible to evaluate these against recognised criteria for environmental assessment purposes.

Natural selection produces an ecological balance with respect to genetic factors but with each alteration in the environment the balance of these factors in the population tends to shift. Natural selection also tends to act upon competition within some species. Noise, like other environmental factors, has the potential to upset the balance between individuals, species, prey and predators etc.

Most importantly, if the man-made sounds incorporate the same frequencies used by the animal there is a risk of some degree of interference with the animal's normal processes such as communication, the detection of prey or the detection of predators. In fact, due to an animal's dependence on either finding sufficient food or avoiding predation in order to stay alive, the more information they can obtain from acoustic signals as well as other sensory stimuli the better. For example, flight from a predator will involve energy expenditure, which would subsequently need to be replaced, and may also needlessly expose the animal to the predator. Therefore, it may be most efficient for an animal only to flee as a last resort, in which case the animal needs to tell the nearness or rate of approach of the predator.

If an animal can detect not only the presence of a noise or its absolute noise level, but also its rate of change relative to the ambient noise climate then it may be possible for some animal species to derive more information that will benefit its survival chances. It will be seen from some of the animal responses to noise stimuli discussed in Chapter 2 that there appears to be a possibility that some species may be able to use the temporal noise changes in such a way that enables them to establish either their closeness to a source of noise, or the speed with which a source may be approaching their habitat, which enables them to determine the extent of the threat and hence the most beneficial/effective type of response warranted by the noise change. In contrast, complex sound sources such as the multitude of different noise sources and tonal frequencies that are associated with helicopters, do not appear to allow the same analysis by animals, which may explain why helicopters tend to elicit more responses than other noise sources.

Finally, in considering the potential effects of noise on animals and their possible responses, it needs to be acknowledged that some species may not be at all bothered by noise levels or noise change, or may fully adapt to changing circumstances without any adverse effect on their biological development. Clearly, the increasing presence of foxes within the urban environment indicates that they are not dissuaded from foraging for food in areas that will have higher background noise levels than rural areas. Birds of prey have suffered most from the progress of civilisation due to the destruction of food supplies and the widespread use of pesticides and other chemicals causing sterility and occasionally death. Nevertheless, some species such as peregrines, have, like the fox, become acclimatised to urban habitats, which although they are noisier are free from poisoned foods.

The presence of crows, jackdaws and magpies scavenging alongside our busy motorways is also a common occurrence. In effect, these creatures choose to spend the majority of their time in a zone that will comprise some of the noisiest land within the country. Anecdotal evidence from Asia indicates that similar species of birds likewise use the urban roads not only for obtaining food but for accessing otherwise unobtainable food. For example, they have been seen to place nuts in their shells in front of stationary vehicles at traffic lights so that the nut is broken open by the departing vehicle and exposed or crushed for easy eating. In a similar manner, in Scotland I have observed house sparrows (*Passer domesticus*) alighting on to the front of vehicles parked alongside the road and eating insects that have impacted against headlights and the windscreen. In all of these cases, the presence of noise has not deterred the birds from exploiting to their advantage a potentially dangerous, and certainly noisy, environment.

1.5 Noise Criteria

In the case of the study of noise effects on man, numerous standard procedures exist for the measurement and prediction of noise and vibration from existing and proposed developments. National and international standards exist in relation to roads, railways, aircraft, industry, and construction sources, and the transmission of sound and vibration within different media, and noise units have been devised that relate to the subjective annoyance or health risk produced by a given exposure. Standard assessment criteria are also available for quantifying the impacts on humans and, hence, determining the acceptability of development or the need for mitigation.

However, apart from a few noise standards applied by the military, which are described where applicable in Chapters 2 and 3, no established methods or criteria exist for the routine assessment and evaluation of noise and vibration impacts on animal communities, or the possible consequences with regard to animal behaviour. In the case of low-level flying, the minimum height normally permitted for military aircraft is 250 feet, although with appropriate authorisation low flying down to 100 ft is permitted in certain remote tactical training areas. In the UK, the MoD has applied a maximum permissible noise level of 125 dB L_{Amax} at ground level in order to limit annoyance to humans but no criteria have been developed specifically for animals.

In the USA and Canada some operational criteria have been developed for training areas, for example the U.S. Fish and Wildlife Service (USFWS) recommend that fixed-wing aircraft should avoid flying less than 150m above ground level (AGL) over eagle habitats during the breeding season. Low-level flying aircraft have been excluded from within a radius of 2.5 nautical miles of active osprey nests during the breeding season in the training areas of Labrador and northern Quebec. Other recommendations have excluded aircraft from flying within 625m of foraging habitats and 1,100m of nest sites.

In the absence of specific assessment criteria for animals, where the effects of development are of concern or are included within an EIA, the actual impacts are rarely defined in sufficient detail to contribute to either the planning process or the design of mitigating measures. Ambient and operational noise levels often form a key component of most EIAs, however, these are often measured or predicted using the A-weighting scale, which reflects the auditory sensitivity of the human ear, since this is of most relevance with respect to noise effects on man. It will be seen in due course how the auditory sensitivities of animals often vary considerably from those of man which, coupled with the effects of the animal's habitat on noise transmission and perception, means that reliance upon dB(A) noise levels for evaluating noise effects on animals would be inappropriate in some cases.

1.6 Research Development

In the absence of recognised procedures and criteria for assessing the effects of noise on animals, this research's main objective was to see whether a set of noise criteria for animals could be developed from the database of existing studies that have been undertaken with respect to noise effects on animals. Chapter 2 provides the results of a review of the existing literature, which looks not only at the various documented responses of different animal species to different noise sources and levels but also at the possibility of using the information to define noise criteria that can be applied to environmental assessment studies. The different types of physiological and behavioural responses are defined together with the implications such changes have on important matters such as feeding, energy balance, thermoregulation, reproduction, prey-predator relationships and hence overall survival.

It will be seen that although some animal responses can be common amongst different species, for example moose, bears and wolves tend to demonstrate similar responses to exposure to aircraft and aircraft noise, other responses can be species specific. For example, on exposure to helicopter noise some bird species respond by flight, others stay on their nests, and others adopt an attack response. Each different response will have different implications for the animal in terms of energy use, risks to themselves or their offspring, and physiological changes necessary to cope with the response. Finally, responses can materialise as group-specific differences, i.e. different groups of the same species can respond differently. The response of a single animal, which may be influenced by the health or general well-being of the individual, or indeed numerous other factors, may trigger the flight of the whole group even though under normal circumstances an adverse response would not be expected.

Consideration is also given to the hearing characteristics of different animals. The range of hearing sensitivities for different species are defined as far as current research allows, which enables the frequency characteristics of a noise source to be linked to the frequency response of exposed animals.

Much of the available data relating to behavioural responses stems from studies undertaken with respect to military developments, therefore, consideration is given in Chapter 3 to a comparison of military and civilian noise sources. The chapter looks at the available noise data for various sources within each of the two categories with a view to establishing the applicability of noise exposure/dose response relationships from one category to the other.

The research considers the derivation of noise guidelines for animal exposure, however, the tremendous variability that is shown to exist between not only different species but also between different individuals within the same species or to different occasions of exposure to the same source indicates that site specific assessment will often be necessary. To this end the research progresses to define procedural steps that should be taken in order to fully evaluate potential noise impacts during an environmental assessment.

As part of the procedure, those aspects of noise transmission that are likely to affect the level of noise, and hence response, at an animal's position have been identified together with other factors affecting animal responses. These factors are used in Chapter 4 to develop precautions and methods that should be applied to obtaining information for assessing the environmental impact of noise on animals. This is followed in Chapter 5 by an analysis of the reviewed animal responses and formulation of a proposed method for carrying out environmental assessments, which it is intended could be formally adopted to ensure that all relevant and appropriate factors are considered by an EIA.

Demonstration of the application of the proposed procedural method is presented in Chapter 6 using the Otterburn Training Area (OTA) within the Northumberland National Park as a case study. The National Park contains numerous protected and sensitive animal species, and the recent and proposed changes to military training at OTA provide the opportunity to determine potential noise impacts and establish mitigation needs using a structured approach. The chapter also includes a retrospective application of the assessment procedure to a location where adverse animal responses have been published – i.e. the effect of low-flying jet aircraft upon animals at Kirkcudbright Wildlife Park.

Finally, Chapter 7 presents conclusions and suggestions for further work.

2. NOISE AND ANIMALS

A review of the literature pertaining to recorded responses of animals to identified noise sources has been undertaken and is summarised in this Chapter. The effects of noise are described in terms of the different physiological and behavioural responses, and where possible, effects have been categorised according to the different types of environmental sources frequently encountered, e.g. road traffic, impulse noise and sonic booms, fixed wing aircraft, helicopters, artillery and industry. (A consideration of marine sources is provided in Appendix IV.) This information forms a key part of the later derivation of an assessment procedure in Chapter 5, and it is supplemented here with a further review of the differing ranges of hearing sensitivity in animals, since this will be an important factor for consideration alongside the frequency content of the source noise.

2.1 Effects of Noise on Animals

Noise may produce a number of different responses in animals, which may be classified as either physiological or behavioural. Physiological responses include effects on hearing, startle responses causing stress, effects on other body functions, and in extreme situations audiogenic seizures. Some strains of mice and rats are naturally susceptible to audiogenic seizures and dietary deficiencies or intakes of specific chemicals can affect the degree of the seizure[11,12]. Audiogenic seizures tend to involve an initial startle followed by a running fit, collapse, convulsions and possible death from respiratory arrest. A sound pressure level of 112 dB at 6 kHz was found to induce typical seizures in the MRL/1 mouse strain, although inhibition of the 'wild-running' phase of the seizure by physically restricting the animal's activities prevented the seizures, which suggests that an excessive physical load on the body is a principal requirement of entering a full seizure[13]. It would appear that mice are more susceptible to death and this may be due to the additional effect of overheating in a small warm-bloodied animal caused by the extreme physical load during the running fit as well as the thermogenic effects of adrenal hormones discussed below. Seizures have been shown to produce a small but statistically significant increase in brain temperature in rats[14], due to increased blood flow, and similarly, psychological stress in rats, which would be a component of most noise exposures causing a startle response, has been found to be accompanied by an increase in core body temperature[15].

In response to stress the body quickly produces heat shock proteins (HSP) to protect cells from heat and other stressors. HSPs are believed to assist in the regeneration, translocation and stabilisaton of proteins after cell damage due to exposure to stressors such as noise. Japanese quail exposed to loud noise (rock music at 68-77 dB) showed an increase in one type of heat shock protein (HSP70) in myocardial tissue[16], and longer periods of tonic immobility (a typical fear response) were also observed but only in response to noise and not other stressors studied, i.e. restraint, irritation, cold, isolation and social situations).

Audiogenic effects tend to be restricted to fairly sustained exposures to very high noise levels such as those used within the laboratory for experimental purposes rather than the level likely to be encountered from environmental noise exposure. However, where noise exposure causes an animal to enter a 'wild-running' phase it would seem likely that if the animal does not calm down within a reasonable period of time, e.g. the noise may be repetitive or continual such that the physical activity is sustained, there may be a risk of a seizure condition being triggered.

Physiological effects that are not visible to an observer include changes to body levels of serum electrolytes, blood sugar, adrenal and plasma cholesterol, blood eosinophils, and free fatty acids, and the effects of vasoconstriction.

Behavioural responses include escape or avoidance reactions, effects on reproductive performance, and interference with communication and detection of prey or predators. In the short term, behavioural responses following a startle reaction may result in energetic costs to individual animals, potential injury, breaking of adult/young bonds, interruption of the incubation cycle, or abandonment of nests. Long term effects would materialise if population numbers change significantly or if high quality habitats are abandoned.

Generally, an animal must first recognise a sound in order to initiate an appropriate response, which involves signal-processing delays within the central nervous system. However, the startle response provides an immediate and primitive reflex[17] to certain stimuli, which helps to protect animals from attack and accident. In some instances, physiological responses are so swift that bodily changes have occurred before an animal is aware that it has been startled. Initial changes include increased heart rate and cardiac output, reduction of blood supply to the digestive system and other non-essential parts of the body, and the transfer of glucose reserves to muscles likely to be used. Any habituation to these startle responses is slow, and in the case of high noise levels the cardiovascular element of the response never fully habituates[18]. In this way the animal is well prepared to fight or flee the source of the disturbance. In laboratory animals, the startle reflex appears to be triggered by impulsive sounds exceeding 80 dB, at frequencies within the range of best hearing having onset rates of more than 20 dB/sec[19].

2.1.1 Physiological Responses

Physiological effects due to noise may materialise within the cardiovascular system (heart and blood flow), the endocrine system (hormonal), the reproductive system, the somatomotor system (muscle control), the nervous system and metabolic systems (energy conversion and growth). In each case, effects may vary according to whether the exposure is short or long term. Many studies on noise effects have used rats because physiological responses on this animal can often be monitored using non-invasive techniques, i.e. by measuring blood flow in the tail, which will lessen the interference of non-noise effects on behavioural response. In this way, blood pressure can be repeatedly measured. Hearing thresholds can also be measured by behavioural techniques; the species lifespan is only 2-3 years, which enables a regular supply of large numbers of animal subjects at all ages; and several species provide a number of different risk groups.

Endocrine system

Of the physiological responses to noise, endocrine changes tend to come first in the sequence of an animal's bodily responses to noise and will arise from only short periods of exposure to noise. Therefore, they represent a useful stress indicator[20], although only within laboratory animals where they can be measured. For animals in the wild, consideration of endocrine noise effects can only be qualitative. Nevertheless, many studies have been undertaken of the 'fight or flight' responses that are initiated by secretions from the adrenal gland.

The adrenal gland, following its activation by the sympathetic nervous system, secretes catecholamines that cause rapid changes in heart rate and the mobilisation of stored fuels for use by muscles and organs. The main catecholamines are the hormones epinephrine (adrenalin) and norepinephrine (noradrenalin), the latter being the major neurotransmitter of postganglionic sympathetic nerves, and they are stored in dense-core granules within the gland. Secretion is mediated by the release of acetylcholine, which is the preganglionic sympathetic neurotransmitter, and cortisol induces the enzymic biosynthesis of epinephrine from norepinephrine. Catecholamines have a relatively low affinity for their receptor and are inactivated rapidly, which effectively means that once an individual has overcome the initial startle it can develop calming responses as soon as practicable. There are several mechanisms for removal of free hormones although approximately 90% undergoes reuptake by sympathetic nerve endings in the adrenal medulla.

Secretions of catecholamines from the adrenal gland cause a rise in plasma catecholamines, which in turn act on the cardiovascular system, though the latter is also directly innervated by the sympathetic nervous system as part of the fight-or-flight response. Their release causes increased heart rate, vasodilation of arterioles in muscle, general venoconstriction and mobilisation of liver glycogen and free fatty acids. They also increase blood pressure, blood glucose and oxygen consumption, and rapidly increase cellular metabolism, which generates heat and hence possible changes to body temperature discussed earlier.

Rats exposed to 1, 6 and 12 hours of continuous noise exhibited ultrastructural changes of endoplasmic reticulum and mitochondria at all exposure times[21]. Diluted cytoplasmic areas appeared in noradrenaline-storing cells after 6 hours and in adrenaline-storing cells after 12 hours. Prolonged exposure (100 dB(A) at 0-26 kHz, 6 hours a day for 7 or 21 days) produced more prominent structural and functional changes within the adrenal gland, and corticosterone plasma levels increased significantly over time[22,23]. After repeated exposure, noradrenaline levels were significantly higher than in controls and adrenaline decreased significantly, leaving adrenaline cells with wide homogenous cytoplasmic areas and large pale vesicles[24].

Dogs exposed to 75 dB, 0.25-8 kHz, for 3 minutes showed the following sequence of events[25]: mean arterial pressure and heart rate increased at 30s and returned to normal at 4 min.; adrenal secretion of epinephrine and norepinephrine increased at 1 min. and remained elevated until 4 min.; adrenal blood flow increased between 2 to 4 min.; and plasma adrenocorticotropic hormone (ACTH) increased together with an increase in cortisol secretion. Rats exposed to novel or familiar stressors showed a reduced release of ACTH in the case of familiar stressors but amounts of corticosterone did not differ[26]. Other exposures (90 dB at 2-22 kHz) have produced a normal ACTH but an enhanced corticosterone in response to 180 min. noise exposure for 18 days, and an increased ACTH but normal corticosterone for 540 min exposure/day for 8 days[27]. Control animals exposed to an ambient noise of approximately 64 dB showed no significant changes to any of the parameters over 18 days.

In the case of virgin or lactating female rats, noise stress (10-minutes of white noise at 114 dB) caused the usual increase in ACTH and plasma corticosterone in the virgins but there was no significant response in the lactating animals[28]. Virgin animals also displayed various behavioural responses not displayed by the lactating females, although the latter did show some activities directed towards the pups, which is not unexpected given the circumstances. The fact that the lactating females did not show the normal response to noise stress implies that the maternal instincts may over-ride the physiological responses at least in relation to mild stress.

With regard to adrenal function, low frequency sounds (115-118 dB at 15-50 Hz) produced increased muscular fatigue in mice[29], and interestingly, low frequency sounds affected deaf animals as much as hearing ones, which demonstrates how the body can be affected by non-auditory routes. In rats, a few weeks intermittent exposure to 95 dB noise during 6 hours/day for 5 days, followed by 3 days off, produced an increased weight of the adrenal glands plus an increase of catecholamine and free fatty acids in plasma[30]. An exposure to 120 dB broadband noise for 2 hours daily produced an increased weight of the adrenal gland but a decrease to the thymus and spleen[31]. The weight change reached a maximum after 7 days exposure but returned to normal within 14 days exposure, which indicates physiological habituation.

High noise levels can cause changes to the immune system. Young mice exposed to noise stress (100 dB for 1 hour) showed an increase in thymulin serum level and an increase in thymus weight and thymocyte number compared to control animals[32]. Exposure of 3-month old mice to periods of low frequency (≥90 dB at <500 Hz for a total of 216 hours) also affected the immune system by accelerating the symptoms of an autoimmune disease within a species prone to disease[33]. Changes to the immune functions of rats has also been observed following acute noise exposure[34], which produced a significant increase in plasma corticosterone level, thymus weight and cell count, and a significant decrease in spleen weight and cell count.

There is in fact great variation between studies, which is possibly due to the wide range of hearing sensitivities within the animal kingdom and the consequent existence of 'harmful ranges' of sound frequencies and intensities in different animal species.

The general findings of most of the studies is that short-term exposures, even at levels equivalent to the industrial environment activate the adrenal glands in experimental animals.

Cardiovascular System (short term exposure)

Exposure to loud noise can produce vasoconstriction and changes to red blood cell velocity in various parts of the animal body, although much research has focused on blood flow in the cochlea due to the direct effect of loud noise on hearing damage. Observations of the blood vessel within the cochlea during exposure to sound have shown vasoconstriction of the vessels coupled with some 'sludging' of the red blood cells, all of which changes were found to be reversible[35]. These findings indicate that responses such as Noise-Induced Temporary Threshold Shift (NITTS) and Noise-Induced Permanent Threshold Shift (NIPTS) are, amongst other matters, a function of reduced blood flow in the inner ear blood vessels due to vasoconstriction resulting from noise exposure.

Broadband sound stimulation of guinea pigs similarly resulted in changes in cochlea blood flow due to changes to blood vessel diameter, and changes to red blood cell velocity were also observed[36]. Stimulation at 110 dB SPL resulted in an increase in red blood cell velocity (maximum 27%) for the first 20 minute of exposure followed by a gradual decrease (minimum –12% below the baseline condition) prior to ending the noise exposure. These changes were due to changes to blood vessel diameters. In contrast, exposure to 84 dB SPL caused an increase to blood cell velocity (maximum 20%) and vessel diameter throughout the exposure. This study indicates that a threshold value exists below which vasoconstriction in the ear will not occur. In this case, the value of 84 dB at which vasoconstriction did not occur lends some support to the assessment threshold proposed later in Section 5.

Further studies using the guinea pig exposed to white noise at 120 dB SPL[37] also found a reduction in cochlear blood flow, although animals exposed to noise while breathing carbogen (10% CO_2 and 90% O_2) had an increased blood flow, i.e. increased oxygen intake compensated for the hypoxia caused by the decreased blood flow. A specific cause of vasoconstriction within the cochlea of the guinea pig[38] has been identified as 8-iso-prostaglandin F(2alpha), which is both a marker for reactive oxygen species and a strong vasoconstrictor, and whose generation as a consequence of noise exposure caused a dose-dependent reduction in cochlear blood flow. In turn, studies with the rat[39] have demonstrated that threshold shifts due to noise exposure are reduced in the presence of substances that scavenge or block the formation of free O_2 radicals.

In the case of peripheral blood flow, early studies on humans have shown that vasoconstriction can be dependent on the physical characteristics of sound[40] and in some cases may be associated with a specific noise threshold; vasoconstriction can also increase as a function of bandwidth. Sound increasing in level and frequency produces greater vasoconstriction than a steady sound[41], and since a predator approaching an animal will similarly produce noise increasing in level and frequency as it gets closer, a similar response can be expected. This ability to equate noise level with source distance is common to many species and may be used to determine at what moment a response, such as flight, to a potential threat becomes worth the energy expenditure. There is also a possible frequency dependency in different species, e.g. there is a pronounced frequency dependency for the psycho-galvanic response in mice[42].

Sudden sounds redistribute blood from the skin and internal organs to the limbs[43] in readiness for flight or fight, for example in dogs there is a decrease in the blood flow in the mesenteric and renal vessels but an increase in the hind limb blood flow[44], which prepares the animal for springing forwards in attack mode. In rabbits, there is a similar decreased flow in the vessels of the kidney, but in contrast to the response of the predatory dog there is also a decreased flow to the muscles[45]. This may be because this animal tends not to run as a first response but to stand stock still and listen. Reduced blood flow to the limbs may help the animal to remain motionless. In contrast to these vasoconstrictions, the rabbit does show an increased blood flow in some parts of the brain, e.g. the inferior colliculi, which represents one of the main synaptic areas of the ascending auditory pathways within the brain. Therefore, increased blood flow to this area may aid auditory sensitivity or response rate.

Just as there can be different heart rates exhibited between different strains and species of animals to a given level of noise exposure, so there are different cardiac responses between individuals of the same species, especially at different ages. In the case of the rat, noise stimuli caused cardiac deceleration in preweaned rats (16 days old) but cardiac acceleration in subsequent ages including adults[46]. (In the same manner, a greater susceptibility to hearing damage or hearing threshold shifts has been found in young rats during the first 5 weeks after birth than in subsequent ages[47], and female chinchillas showed greater resistance to low frequency hearing loss than males[48].) In dogs, the response was an acceleration followed by a deceleration in heart rate, with habituation occurring typically after about 10 presentations of a noise event[49]. In guinea pigs, the majority showed a fall in heart rate whilst some showed a biphasic acceleration/deceleration pattern[50], which perhaps reflects an uncertainty with regard to the noise source and the type of response that the animal should exhibit.

An individual's response to anxiety provoking stressors can enable them to be identified as reactive or non-reactive individuals, and cardiac variables such as heart period and respiratory sinus arrhythmia (RSA) can be used as measures of response. Male and female longtailed macaques (*Macaca fascicularis*) exposed to two stressors – a sudden whistle noise and an unfamiliar technician wearing capture gloves – showed varying degrees of decreased heart period and suppressed RSA[51]. Within 10-minutes of the exposure to whistle noise, the cardiac activity tended to return to baseline, but the presence of the unfamiliar technician wearing capture gloves produced more extended suppression and also greater variation between individuals. This stronger reaction to humans is consistent with other environmental studies (see Chapters 2 and 3) that have shown a stronger response to the mere presence of humans rather than the noise that they generate. In the above study, of 16 subjects exposed to the 'glove' test, five individuals were identified as reactors, and this illustrates the difficulty in defining species responses when individual differences occur within the same species.

Noise stress can also produce ultrastructural changes to myocardial tissue[52,53], especially at the mitochondrial level. After 6-hours exposure to noise, mitochondrial changes were observed in atrial tissue of rats, and after 12 hours exposure the mitochondrial damage extended to both the atrium and the ventricle[54,55]. Observed damage following 6-hour exposure to audiogenic stress has been swollen mitochondria and enlargement of the space between the outer and inner membranes of the mitochondria[56], and a decrease in the number of mitochondrial binding sites[57]. Further studies have indicated that these noise-induced morphological changes are due to calcium accumulation[58].

The above mitochondrial changes have been found to be more marked in male than female rats[59], which indicates that different responses to noise stress are possible between different sexes as well as different individuals. Similar effects have also been observed within the mouse myocardium, although quantitative analysis of the altered mitochondria in both species showed a significant difference between the mouse and rat myocardia[60], which suggests that in this respect the two species have differing sensitivities to noise.

With respect to blood pressure, emotional sounds, e.g. animal distress calls, cause a more pronounced effect and more slowly habituating reactions than pure tones[61]. Blood pressure is altered by exposure to noise, however, most laboratory tests on animals have tended to use very high noise levels that are not normally encountered in the natural or urban environments. Therefore, care has to be taken in the application of some research findings to real-life circumstances.

Cardiovascular System (long term exposure)

After long term exposure to a noise there can be rapid habituation to sounds with minimal information, but on-going responses to sounds signalling discomfort or intense activity[62]. The following examples deal specifically with responses of the cardiovascular system but because exposure is long term they also often provide examples of habituation. Further examples of habituation are provided throughout this research, for example see page 46 of this Chapter, however, the topic is poorly studied and warrants further assessment.

The heart rate of lambs showed complete habituation to music but not to white noise after an exposure of 11 hours/day of intermittent and dissimilar sounds for a period of 12 days[63]. Monkeys exposed to traffic noise of L_{A10} >84 dB for 12 hours/day showed an initial increase in heart rate followed by a decrease after a few weeks of exposure[64]. However, it is possible that the decrease is due to a slow rise in blood pressure reflexively affecting the heart rate. Some individuals showed an anticipatory heart rate reaction in the morning before the start of exposure, which is an example of conditioning.

In rats, exposure to 5 minutes of compressor noise every day produced a rise in systolic pressure after 200 days[65]. There was also a rise in heart weight after 3 weeks exposure to intermittent noise, indicative of sounds causing an increased workload due to hypertension. Such experiments suggest chronic sound exposure can cause a moderate rise (up to about 160 mm Hg) of systolic blood pressure. Exposure of 14-week old rats to recurrent buzzer noise (100 dB at 500 Hz for 6 seconds during every 30 second period over a total exposure period of 35 days) produced an immediate increase in blood pressure and heart rate, but habituation occurred rapidly in that measured ‘movement responses’ fell from 75% in hour one to 20% in hours two through to seven in day one[66]. Movement responses reduced further by day 35, although they remained higher than for control animals not exposed to the noise. Both blood pressure and cardiovascular responses showed signs of habituation, and there were no sustained increases after exposure ceased. Habituation was also found in baboons, which showed initial transient increases to blood pressure and heart rate when exposed to industrial noise for 8-hours[67]. However, chronic noise exposure lowered the blood pressure and the heart rate both during exposure and after the daily offset.

Sound deprivation, i.e. keeping animals within a low noise environment of 32-35 dB, was observed to caused an increased blood pressure in rats compared to rats exposed to traffic noise (75 dB)[68]. However, in the latter case, noise may mask out otherwise informative noises, e.g. aggressive actions or distress calls that would be more evident in the low noise environment. This suggests that in some instances extraneous noises might conditionally have the potential to minimise some physiological responses. Further research is required to establish the degree to which this might be beneficial to some species or groups of animals.

One problem in determining the effect that noise may cause is that responses can be determined not only by environmental influences but also by genetic predisposition. A comparison of spontaneously hypertensive rats with a normotensive species of rat exposed to a 65 dB, 4 and 250 Hz tone for 52 weeks showed increased microvessel wall area, cardiac fibrosis and ischemic myocardial lesions in the hypertensive but not the normotensive species[69]. Similar differences relating to blood pressure and heart rate have been reported for different genetic strains of rat exposed to an acoustic startle stimulus[70] and strong genetic influences have also been found for the acoustic startle response in mice[71] and rats[72].

Reproductive system

Noise can also have an effect upon the reproductive system. The applications of stressors (noise, handling and chasing 5 times/day for one month) inhibited follicular growth in lizard ovaries[73], and acute and chronic noise exposure in laboratory rats can influence excretion of gonadotropic hormones and the function of ovaries and testes, and also lead to decreased fertility and increased rate of malformations[74,75]. Early studies[76] also suggested that the auditory masking/interruption of ultrasonic communications from baby rats caused adult rats to kill offspring. However, later studies with deaf mice[77] found that these showed no greater tendency towards cannibalism towards their young than hearing animals not exposed to noise, which suggests that aggressive responses towards young following exposure to noise is more likely to be attributable to auditory stress effects.

Noise can also have a direct impact upon a developing foetus, and the level of noise exposure has been found to be dependent upon the position of the foetal head within the uterus[78]. For impulse noise exposures averaging 168 dB peak SPL in air, the noise level at the foetal head of sheep was within 2 dB of the airborne level when the head was against the abdominal wall but the level reduced by up to 10 dB or more when the head was deeper in the uterus. Following exposure the foetus' auditory brainstem response (ABR) exhibited low frequency threshold shift.

As previously mentioned, sounds received by an animal can contain information besides that represented by the sound level, for example, the tape-recorded sound of calves has been found to cause increased milk yield in cows[79]. This effect was considered to be due to secretion of oxytocin, but what is important is that the information content of the sound was more important than the noise level.

Metabolic System

Noise exposure can produce decreased body weight, or slower weight gain, and decreased food intake[80]. In rats exposed to what was referred to as mild subchronic noise stress (95 dB white noise for 45 min/hr, 12 hr/day for 8 days), plasma corticosterone levels increased twofold and microscopic examination of the ileum showed marked changes to intestinal barrier function[81]. Such effects could have a short term effect on energy uptake and if continued long term would influence body weight or the ability to sustain energetic activity.

An exposure to a natural noise source, thunder (98-100dB at 150 Hz) caused increased oxytocin release in rats[82]. Similar events also caused salt and water retention, and preservation of blood volume and pressure, which are physiological responses consistent with a preparation for fight or flight.

Somatomotor system

The startle reflex is the best known physiological response of an animal to noise and it represents a generalised muscle response and flexor muscle activity. The similar but opposite and less visibly obvious response is the 'freezing' reaction, which represents a decrease in electrical activity. This response is exhibited by animals such as rabbits and hares as discussed above. In some species, for example cats, both increases and decreases in spinal reflexes can arise in response to noise[83,84].

Nervous system

A key element of an animal's fear response to acoustic and other stressors is the very short time that signals take to travel between the auditory system and subcortical areas of the brain, e.g. the amygdala, hippocampus and hypothalamus[85]. One such link is a monosynaptic connection or projections from the auditory thalamus to the amygdala, which has been identified as an important factor in conditioned fear responses to acoustic stimuli[86]. In effect a 'fear memory' route enables an animal to instantaneously evoke those behavioural characteristics needed to successfully respond to the fear/threat. Although conditional stimuli will elicit firing of lateral amygdala neurons, the neuronal firing is tempered according to other contextual information provided along with the conditional stimulus, which enables an animal to 'select' an appropriate fear response to suit the triggering factors[87].

Environmental stress/noise can cause an increase in sympathetic nerve activity. Rabbits exposed to 10-minutes of white noise at approximately 85 dB produced increased renal sympathetic nerve activity, which was greatest in the first minute but quickly declined to a stable level during the exposure[88]. The increased neural activity was accompanied by a small increase in heart rate and mean arterial blood pressure. In the rat, an increase in exposure time to acoustic stress produced a corresponding increase in sympathetic innervation, which was most evident at cardiac level[89].

There is also evidence that noise exposure can affect the respiratory epithelium in that exposure of rats to taped industrial noise generated in cotton mill textile plant rooms for periods of 40 hours/week over 1 to 7 months caused a significant loss of tracheal ciliated cells, which was balanced by an increased density of serous cells on the epithelium[90]. Other studies have similarly shown 'shaggy' or necrotic cilia, as well as sheared cilia, on tracheal epithelia following exposure of rats to low frequency noise ≥90 dB at <500 Hz[91]. It is not immediately obvious why this change should occur, other than perhaps that this type of cell is prone to damage from sound pressure increases rather like the hair cells within the ear, but then there is similarly no obvious reason why some other physiological changes at a cellular or sub-cellular level occur following exposure to noise. Nevertheless, it is important to recognise that various body-wide changes can arise as a consequence of long-term or loud exposure to noise. Even damage to DNA integrity has been found following the exposure of rats to 100 dB(A) for 12 hours[92]. What is relevant is whether such changes will occur as a result of possible environmental exposures and whether these are likely to affect an animal's ability to function normally within its natural environment.

Other effects might relate to an animal's ability to learn or retrieve information from memory. For example, the effects of predictable and unpredictable intermittent noise levels of moderate intensity (68 dB) on the ability of rats to learn a complex maze showed that noise had a profound effect on learning and behavioural scores[93]. There was no difference between predictable and unpredictable noise and, following further control tests, the conclusion was that the effects of noise on learning were caused by an effect upon memory formation and/or retrieval rather than a direct effect upon behavioural strategies.

The above brief review of physiological responses has identified a number of important issues that need careful consideration when either evaluating the effect of noise on animals under laboratory conditions or assessing the effects of noise on animals in nature. These can be summarised as follows:

- what particular conditions must be fulfilled to produce a harmful chronic effect;
- what physical characteristics of sound are necessary to produce a particular potency of adverse response;
- what information is contained within the sounds;
- are there different short or long term effects;
- are there synergistic effects with other environmental factors;
- does the noise and the consequent response pose a threat to an individual's health, or a decrease to its well being, or an increased susceptibility to disease, or a shortened lifespan; and
- any effects of 'handling', which might themselves produce similar responses to other events, need to be eliminated.

Energy Expenditure

The energy expenditure associated with the above physiological responses, or indeed with the behavioural responses that are discussed later, is likely to be of importance for the well-being of individual animals, especially where individuals may be in poor condition due to ill-health or under-nourishment etc. Young animals, or small species that have much higher metabolic rates, are also likely to be more susceptible to circumstances that cause rapid and increased energy expenditures. Increased energy expenditure from single events probably does not cause any long-term harm to animals since they subsequently have time to recover. However, events that are highly frequent and do not allow the animal adequate recovery time are likely to be problematic.

Although the energetic cost of a single startle may be negligible, it must be remembered that any physiological excitation such as increased heart rate may not only be associated with the energy expenditure due to that physiological response but may lead to subsequent behavioural responses, e.g. flight, that can be significant. Flight is the most energetically expensive activity of birds and accounts for 8 to 14 times the energy associated with the resting state[94,95]. Similarly for mammals, walking/running may use more than 40% more energy than standing. One study[96] indicates that the energy expenditure for a 90kg animal forced to move due to aircraft harassment was 64 kilocalories/minute when running and 20 kilocalories/minute when walking. Another study[97] provides an equation to calculate the energy expenditure of large ungulates as 3 x 0.0001 calories/gm/step.

Birds are unlike other animals because the most energetically expensive activity – flight - is unparalleled among animals for its high and sustained energy expenditures. Some studies have demonstrated that the energy expenditure due to occasional or intermittent disturbance represents only a small part of the total daily energy budget[98], therefore, birds that do not normally fly a great deal but are forced into flight by disturbance will be most susceptible to energy loss. Moulting, the shedding and regrowth of flight feathers, is accompanied by changes in the relative mass of the muscles between the legs and wings[99]. As a consequence, the energy demands of moulting birds, e.g. waterfowls, can be expected to be relatively high.

Smaller animals such as weasels, martens and fishes tend to be more sensitive to changes in energy balance[100], mainly due to the fact that the metabolic costs for smaller species are greater than those of more spherically shaped mammals of the same weight due to their relatively high surface to volume ratios[101]. Smaller animals also rely on speed to catch their prey, therefore, they store little energy or body fat that would otherwise require the carrying of extra body weight which would in turn lead to slower movements. Their underfur is also generally shorter, which increases their thermo-regulation costs during cold periods[102]. As a consequence, any noise effects that disrupt the normal feeding habitats and lead to short-term energy losses must be recouped immediately, e.g. by increased foraging, which will in turn place further energy demands on the animals. Long-term noise effects on such species in areas where food is not particularly abundant, or during cold conditions, may be particularly disadvantageous and might lead to adverse health effects.

Factors that influence thermal regulation cannot always be considered in isolation because they can have greater effects in the presence of other substances or conditions. For example, noise, carbon monoxide (CO) and temperature can have very significant single effects on the variation of some animals' deep body temperature (dbt) values[103]. The effects of any two factors had a very significant combined effect on the variation of the dbt-values. For example, when animals were exposed simultaneously to 750 parts per million (ppm) CO and a 105 dB(A) noise at 40 °C the increase in dbt-values was very significant. However, this does not provide any useful indication of the likely implications in environmental situations because such CO concentrations would not be present under non-laboratory conditions.

2.1.2 Behavioural Responses

Specific acoustic features that have evolved to provide an animal with advantages re: survival or predation may subsequently be disadvantageous with respect to exposure to modern noise sources. For example, the ears of the kangaroo rat have become adapted to amplify low frequency sounds produced by predators such as the sidewinder rattlesnake. This adaptation affords them little protection against high intensity low frequency sounds such as those produced by the engine and exhaust noise of off-road vehicles (ORV) such as dune buggies and trail bikes. Exposure to levels of 95 dB from these sources produced hearing impairment that lasted for up to 3 weeks[104]. During this recovery period, affected animals would be particularly susceptible to predation.

The energy costs associated with a particular disturbance need to be placed into perspective if the potential implications are to be evaluated correctly. For instance, of the various circumstances studied in relation to arctic mammals, it would appear that the highest daily energy expenditures recorded coincided with increased activities and stress caused by insect harassment[105] rather than military activities. Likewise, although aircraft overflights and vehicular traffic within 200-400 m of sheep produced increased heart rates[106,107], and helicopter overflights caused a 2 to 3.5 increase in heart rate requiring a recovery time of 20-65 seconds, the approach of humans and dogs elicited the greatest response.

With regard to farm animals, exposure to simulated sonic booms (an air overpressure of 200 N/m^2) produced a startle response but eating patterns and feed intake were unaffected[108]. Pigs have been exposed to noise levels of 100-120 dB without causing any impact on conception rate or weaning. Noise levels of 80 dB have had no effect on the milk yield of dairy cows[109], though continuous exposure to 105 dB did produce reduced feed consumption and decreased milk yield. In practice, levels of these orders are unlikely to be routinely encountered other than in very extreme circumstances.

Although some songbirds and terrestrial mammals have similar audiograms to humans, many others do not. Many mammals with a body size less than humans use auditory frequencies >20 kHz, i.e. ultrasound, for communication and location. Since high frequency sound attenuates very rapidly, it is to be expected that any adverse effects will only be encountered close to the noise source. Therefore, only limited effects should be encountered from normal audio frequency sounds on animals utilising ultrasound.

Infrasound attenuates less in air and can have long distance effects, but there are difficulties in studying the effects because it cannot be heard by humans and is difficult to generate and control. Animal sensitivity to infrasound is known, for example in birds, Rock Doves have nearly 40 dB more auditory sensitivity than humans in the 1-10 Hz range[110]. In addition, the nervous system of pigeons responds directly to infrasound[111], though it would appear that this is a direct reaction to the waveform rather than the normal acoustic parameters. This may enable them to respond to the exact waveform of sounds such as helicopter noise rather than to the usual acoustic parameters[112]. Also, insects, elephants and possibly other large mammals use infrasound for communication[113].

Songbirds often go silent about 4-8 seconds before the arrival of the audible sonic boom; this coincides with the arrival of the seismic signal, which is propagated through the ground at a greater velocity[114].

Wind noise itself can be an important component of noise levels received by animals though there appears to be little consideration of this in the literature. The potential effects can be classified as either non-laminar flow over the sensor itself, or flow over other objects causing pressure changes to be transmitted to animals in the vicinity. In theory, the natural selection process should have prevented the former from being a problem for the animal, though situations where new development introduces new structures that have an effect on wind flow patterns and characteristics may be of relevance.

Loud noises already form part of the natural environment due to events such as thunderstorms, landslides, earthquakes, crashing icebergs, waterfalls, winds and volcanoes. In most cases, animals are more likely to be closer to these sources and already exposed to levels of intensity that may not be particularly different to levels generated by man-made sources.

Habitat characteristics can distort sounds, causing different arrival times of direct and scattered sound waves[115]. For any study of noise exposure in an animal's habitat it is important that any noise measurements or prediction points correspond to the same habitat and to the same height and relative location etc. within the habitat as that actually occupied by the wildlife, so that all relevant factors affecting the propagation of noise to an animal will be accounted for. For instance, animals occupying vantage points above ground may hear more or louder noises due to less screening, whereas those living close to the ground or within burrows will experience substantially less from the same source. Unfortunately, noise monitoring can often be adversely affected by the actual vocalisations of the species being monitored, e.g. birdsong, such that accurate measures of the noises of concern are not possible.

The type of habitat can also influence the extent to which animals use sound for communication and location etc. For example, the songs of forest birds include less temporal detail[116] and this is probably due to natural selection in an environment where sound is blurred due to vegetation causing absorption, scattering and screening of sound.

Animals receive acoustic information via the normal characteristics of sound such as frequency, modulation, amplitude and temporal features such as the duration and spacing of notes[117].

Natural selection also leads to situations where animals avoid conflict with other species, e.g. the timing of vocalisations during the day by certain species of frogs and cicadas to avoid communication conflicts[118]. Animals are probably able to detect whether sources of noise are near or far without the need for visual cues, and they probably do this through using factors such as an altered spectrum, different sound intensity or the blurring of sound clarity with distance[115,119,120]. A sudden onset of noise is especially apt to cause a startle reaction, although distant sources are more likely to have a slurred or rumbling onset that may reduce the reaction.

The actual effects of noise are most often species specific, therefore, noise effects cannot be generalised, especially for environmental impact assessment purposes, since the impacts may be different from one species to another. Different species of birds have different hearing thresholds, which will result in differing responses to the same noise[121]. Different behavioural responses also arise such that for a given exposure to, say, helicopter noise, some species of birds will flee, others will stay on their nests, and others will adopt an attack response. Likewise, species-different responses of arctic mammals such as moose, bears and wolves have been elicited by the approach of aircraft[96].

In 1969, from a colony of 50,000 pairs of sooty terns nesting in southern Florida, only 242 chicks were successfully hatched compared to the usual 20-25,000[122]. Although there was no direct evidence as to the cause of this failure, circumstantial evidence at the time pointed to the newly introduced presence of sonic booms on a daily basis. However, the case was reanalysed in 1991[123] by exposing chicken and quail eggs to explosive impulse noise of 177 dB at a mean frequency of 620 Hz, and none of the eggs developed longitudinal cracks. Fertile eggs were similarly exposed but hatch rates and weights were not significantly different from unexposed controls. Further analysis has been reported[124] using mathematical models to take account of the shape and composition of a typical egg, the peak response of the egg (i.e. the peak shell stress), the embryo acceleration, and the reactive force between the egg and the substrate, which are computed as a function of the incident boom overpressure. The conclusion reached was that overpressures from supersonic aircraft are insufficient to damage bird eggs in general.

Therefore, recent data indicates that direct damage from a sonic boom is unlikely because it is not physically possible to generate sufficient sound pressure in air to break the eggshell or damage the embryo. The resonant frequency of eggs is typically in the range of 400-1400 Hz whereas sonic booms have their peak frequencies at about 10 Hz, nevertheless, even when studies applied the sound energy at the resonant frequency of the egg, damage did not arise. Damage caused by disturbed brooding adults is a possibility but, in contrast, the sooty tern colony also contained 2,500 brown noddies whose young did hatch successfully. Since the damage to eggs did not materialise directly as a consequence of exposure to sonic booms this difference between the two bird species could be said to illustrate how noise effects can be completely different between different species exposed to the same noise source. Unfortunately, there is no evidence to conclude that the adult sooty terns responded any differently to the brown noddies and that it was their behavioural response that caused the damage.

It is also possible to get group-specific differences to the same noise source, i.e. different groups of the same species can respond differently. Factors that most affect this type of response are the heightened responsiveness of certain individual members of the group, and social responses within the group. In many situations, the response of one animal can lead to the flight, or other social response, of all members of the group.

Habituation

Habituation is an important factor with regards to the long-term impacts of noise on animal communities. However, it is likely that no study can take place without subjects undergoing some degree of habituation to natural or experimental environmental noise sources, e.g. bird scarers, because habituation represents an active learning process within an animal's normal life experiences[125]. Predictable and recurrent sources of disturbance can give greater habituation than less predictable ones[126]. Irregularity of sound stimulation produces delayed habituation. Habituation to intermittent sounds >75 dB has been demonstrated with rodents[127], domestic sheep[63] and elk[128]. However, even when habituation has occurred, the obvious conclusion that no adverse effects have been caused can be misleading since significant physiological effects may still take place, which would not be immediately apparent through behavioural observation. Animal populations that are actively hunted by other species and only survive due to their alertness and persistent response to external stimuli may never habituate to a disturbance because to do so would leave them open to predation. However, species capable of complex acoustic discrimination can modify their predator responses according to learnt experiences, e.g. wild harbour seals are able to distinguish between the calls of mammal-eating killer whales, i.e. their predator, and fish-eating killer whales and adjust their responses accordingly[129].

The acoustic context is also important with respect to habituation[130]. Albino rats exposed to 60 dB white noise coupled with sudden onset tones of 110-120 dB exhibited startle responses that diminished after several presentations, i.e. habituation took place; however, for exposure of the same tones against a background of 80 dB white noise, the startle responses became successively stronger[131], i.e. the animals exhibited sensitisation. On this basis, the synergistic interaction of two different noise sources in the field may have a greater impact than the effects of the individual components.

Conditioning is another factor that affects an animal's response to noise. In this case, the conditioned response is caused by factors other than just the noise but which the animal links with the noise event. In this respect observational learning may also be of significance. Regular intervals between noises are likely to result in less of an effect than haphazardly timed and varied sounds, and cues just before loud sounds might enable learned tactics to minimise effects. In contrast, sudden onset sounds linked with biological signals, e.g. signalling danger or injury, may induce long-term strong effects.

The damaging effects of noise can be modulated as demonstrated by the 'training' or sound conditioning of guinea pigs to a long term, low level acoustic stimulus prior to a traumatising exposure[132]. A conditioned group were exposed continuously to a 1 kHz tone at 81 dB for a period of 24 days prior to being exposed to a traumatising tone (105 dB at 1 kHz for 72 hours), whereas a control group was only exposed to the traumatising tone. The main findings of the study were that sound conditioning resulted in i) a 20 dB reduction of the auditory brainstem response relative to animals not 'conditioned', and ii) complete recovery of auditory sensitivity after one month. In contrast, the control group continued to show a threshold shift of approximately 25 dB. Similar results have been found for other animal species, e.g. rabbit. Studies on chinchillas[133] have similarly shown decreased amounts of temporary threshold shift (TTS) with repeated exposures (reduction of up to 30 dB) or less permanent threshold shift (PTS) with exposure to high level traumatising noise (10 to 20 dB less than control group).

The activity of an animal during a noise event, or the time of the event, can also affect the response. If an animal is preoccupied with other disturbances, e.g. biting insects, the effects of noise may be lessened[96]. With respect to diurnal effects, there are likely to be different acoustic interactions over a 24-hour period and many animals may rely more on auditory cues at night, especially with respect to feeding or personal safety. Different seasons of the year, and different times within the animal's reproductive cycle, also influence acoustically moderated behaviour. There may also be critical periods during an animal's development, for example songs heard during a specific few months of a young bird exert a permanent influence on the adult bird's song[134].

The animal ear is a transducer susceptible to noise induced hearing loss just as it is in humans. The principal difference between animal and human exposure to noise is that animals are typically not as close to noise sources as humans, e.g. to machine noise and gunfire etc., and as a consequence are not as exposed to high levels of high frequency noise likely to cause auditory damage. Bird colonies on military firing ranges are the exception, although the indications are that these often tend to remain as stable communities, which suggests that the high but intermittent noise levels do not have an adverse effect on the long-term viability of the species at that location. Nevertheless, there is some evidence that young animals in particular are more susceptible to hearing damage, although hair cell regeneration has been observed in birds[135,136,137], which will compensate against adverse physiological effects caused to the ear by high noise levels.

One difficulty in defining the effect of noise on animal responses is that experimental effects do not necessarily reflect true-life exposure situations. It is also difficult to define issues such as disturbance and harassment, especially in a way that can provide an accurate and repeatable measure from one situation to another. In order to quantify any effects on the long-term viability of a community it is very important to look at population trend data – if a local population exposed to noise remains stable and abundant, then any adverse effects on a few individuals (such as the less fit/able) must be insignificant since they do not affect the population as a whole[138]. Unfortunately, this information requires long-term monitoring of communities over many years, which is likely to be precluded from many research studies and also from environmental assessment studies. The potential effects are likely to be of much greater importance when the overall populations of the species are small, i.e. for endangered species.

Finally, it is important to fully understand the implications of an animal's response with respect to not only noise but also other factors, including biological ones, prior to reaching a conclusion. As an example, disturbance to lizards is likely to produce an increased respiratory rate, which considered in isolation might be viewed as harmless to the lizard. However, lizards breathing rapidly do not eat[139], which clearly can have harmful effects with respect to an animal's energy balance.

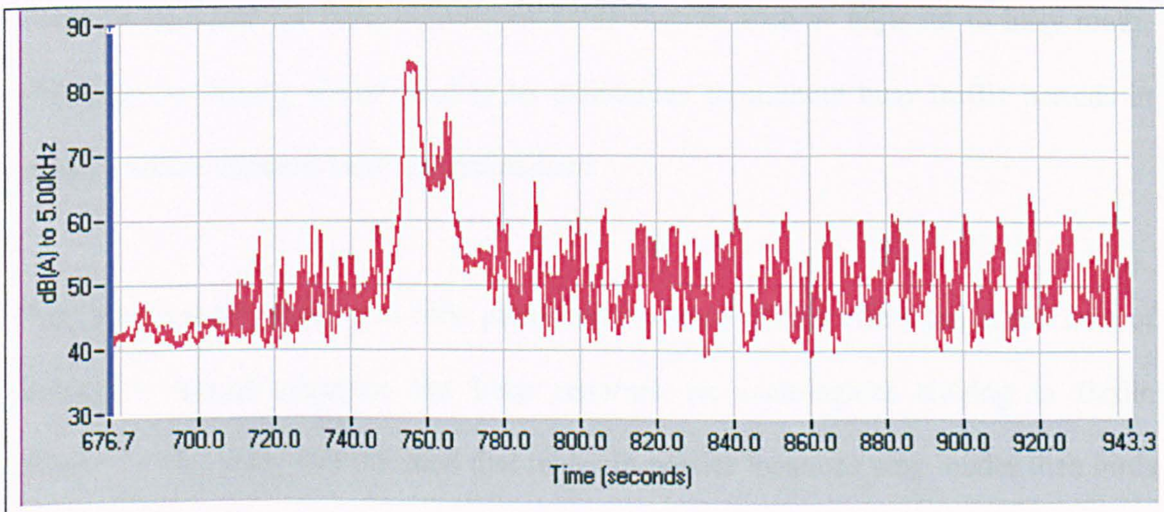
Likewise, landed seals return to water when startled and this in isolation may be considered to have no adverse implications in that the animals have returned to a safe habitat. However, in returning to a colder environment they will increase their energy expenditure due to the changes imposed on their thermo-regulatory system[140], and repeated or prolonged energetic stress in this way will increase use of the protective blubber layer that protects against cold[141], thereby reducing the animal's ability to survive under extreme conditions. Also, whereas in some circumstances an increase in noise level, e.g. adjacent to a new transportation corridor, might lead to a decrease in population density by shifting an animals' home range, in others an increased density might arise as a consequence of reduced territory size due to noise levels masking acoustic displays normally associated with territorial marking.

2.1.3 Author's observation of effects of noise on birdsong

Birdsong is one of the commonest acoustic displays to occur alongside environmental noise sources, and bird communities can be found adjacent to roads, railways, airports, military ranges and most urban and rural development sites. Using a DAT tape recorder and the monitoring equipment identified below Figure 2.1 I recorded noise levels from birdsong adjacent to a mainline railway. The microphone was located in a free-field position 2m above the top of a 3m deep railway cutting and had a direct line of sight to the trains at a distance of 20m. Weather conditions were dry and calm, although weather conditions would not have had a significant effect on either train noise at a range of 20m or on birdsong near the microphone. Birdsong from unidentified birds was present in the vicinity of the microphone and noise measurements were undertaken when train noise and birdsong coincided. On playing back the calibrated DAT tape I observed that the birdsong became distinctly louder as a train passed the monitoring position. The noise trace from the recording is shown in Figure 2.1 and the period of louder birdsong is clearly evident just after the main noise peak due to the train has passed.

The noise trace shows an initial period of birdsong when noise levels from the birds in the absence of other noises tends to vary from 40 to 60 dB(A). The passage of the train increases the ambient noise level to 80 dB(A), and as the train noise decreases birdsong recommences when the decreasing train noise reaches 65 dB(A), at which point the birdsong ranges from 65 to 76 dB(A). As the train noise decreases further and the normal ambient conditions return, the birdsong noise level similarly reduces and returns to a distinct cyclical pattern, typically varying between 40 to 60 dB(A) but with occasional peaks up to approximately 65 dB(A).

Figure 2.1: Noise recording displaying changes in noise level of birdsong during a train passby



Equipment:	CEL-90249 eNVi system hardware with NoiseMaster and FrequencyMaster software; CRL MV 181A Pre-amplifier and cable; MK 224 Precision ½ inch electret condenser microphone + windshield; Fujitsu Siemens B Series Lifebook laptop computer; Sony TCD-D10 ProII Digital Audio Tape Recorder; USB-One High Performance Audio Interface; and Larson Davies CA200 acoustic calibrator. (Calibration 94 dB)

The above data shows that the singing bird increased the volume of its singing as a direct consequence of the increased ambient noise due to the passing train. The noise change amounted to approximately a 15 dB(A) shift to the birdsong peak noise levels. Since the purpose of the birdsong will be to either maintain territory or attract a mate, it can be concluded that, due to the increasing ambient noise, the bird sang louder in order to ensure that its calls remained audible to competitors or mates. In the case of noise from railways, periods of higher noise levels only arise intermittently during the passage of trains and ambient conditions prevail in between each event. As a consequence, the demands upon birds to increase the volume of their calls will not be continuous. On the basis of the above noise recording, which shows an increased level of singing over a 10 second period, a typical train frequency of, for example, 10 trains/hour would only require an increased volume of singing over 100 seconds (i.e. 1 minute 40 s) in each hour. This is unlikely to impose excessive energy demands or other physical/physiological strains on birds that respond in this way. However, the situation would be different for more continuous noise sources such as adjacent to busy roads, where louder singing would need to be maintained throughout busy traffic periods in order to ensure territory areas are maintained.

Until very recently there was little published evidence of this effect but at the time of writing, a similar response has been reported for nightingales singing in Berlin streets[142]. The study has revealed that males in noisier locations sing louder than birds in territories less affected by ambient noises. At one location road traffic noise levels reached 89 dB, which is similar to the peaks monitored adjacent to the railway, and the study found that at weekends when traffic flows were much reduced, the birds sang at a lower level. The study also implied that the consequence of singing louder to overcome the masking effect of the louder periods of traffic noise was that birds developed symptoms equivalent to 'hoarseness and coughing', though how these effects were determined is not evident and further research is required.

The above work can be extended by means of environmental and laboratory studies to establish factors such as the absolute noise level or change needed to trigger the 'on' and 'off' points for increases and decreases in loudness of bird vocalisations, the differences between different species, and the maximum increase that birds can produce, which can be used to determine source limits above which birds cannot compensate for potential loss of territory by louder singing. Increased energy expenditure or any adverse physical responses such as an inability to maintain the louder singing will be particularly important. Exposure of individual caged birds to different source noise levels would enable specific matters such as the on and off thresholds and the absolute change capable of being produced by different individuals and species to be determined. The following sections provide examples of behavioural responses categorised by source type and they include some further examples of the effects of noise on bird calls.

2.1.4 Road Traffic

Nesting sandhill cranes were undisturbed by highway traffic at 4m from the nest or by large trucks at 200-300m from the nest[143]. However, it is not evident to what extent large trucks closer than 200m caused disturbance. With regard to road traffic and logging activities, herds of elk showed less behavioural reaction when forested habitat, i.e. cover, was available close by[144]. The animals tended to avoid open areas within 250m of a road, i.e. in effect a new road affected use of the animal's habitat, but it is not evident from the study whether this effect was a direct response to traffic noise or the numerous other factors that are typically associated with the construction and operation of a new highway. The motion of road vehicles, and changes to the physical environment such as temperature and wind, have also been proposed as factors affecting animal distribution close to roads[145,146].

In a study into the effects of road traffic on woodland breeding bird populations[147], bird densities were compared between 16 plots adjacent to a motorway carrying 30-40,000 vehicles/day and 16 equivalent plots more than 300m from the road. Conditioning factors such as habitat and vegetation were as similar within each pair of plots as possible. The analysis showed that almost all species had a lower breeding density in plots close to the road, and for six species the difference was significant. The results
e indicated three levels of effect representing short, intermediate and long-distanc effects. Of four species showing short-distance and intermediate effects (marsh warbler, willow tit, willow warbler and pheasant) the relationship between breeding density and noise level was roughly linear with effects being observed down to 50 dB $L_{Aeq\ 24\text{-hour}}$. In effect, the results suggested that traffic noise effects might extend to a distance of approximately 500m in willow plantations and open poplar woods, and approximately 250m in dense woodland on the basis of a measured attenuation of 4 dB(A) per 100m. Other studies have demonstrated similar evidence of lower bird breeding densities close to busy roads[148].

However, it is important to note that the numbers of most bird populations can vary from one year to another due to various factors; for example when the population is high and there is competition for food and mates, compensating mechanisms such as immigration will be more important than when numbers are low. In the case of road traffic, there are also factors other than noise that may affect animal populations. Physical contact or collision has been shown to be significant for some species and some sites close to busy roads, but visual stimuli, air pollution and possibly vibration may also have an effect. The three latter factors are thought to be less significant in woodland especially at greater distances, but visual stimuli may be significant in open habitats where they can be visible over a long range. Long distance effects on meadow birds have been attributed to visual stimuli[149].

A study that looked at the effect of aircraft noise on bird calls also included some examination of the effects of highway noise on bird calls for communication purposes[150]. The work indicated that, for the site in question, although bird calls could be masked by traffic noise this did not happen for a sufficient amount of time to disrupt breeding. However, this suggests that if the traffic flows are high enough and continuous enough, and if breeding sites are close to a road, that some degree of disruption might occur for some species. Further study considered whether birds might compensate for higher ambient noise levels by increasing their call rate. However, for a range of locations where ambient noise levels were between 50-75 dB (linear), only the song sparrow (North American species, *Melospiza melodia*) showed a significant correlation between ambient noise level and singing rate. Overall, the scatter in the data implied that higher ambient noise levels did not represent a principal factor in why birds may vary their song rate. In contrast, other studies[151] have demonstrated that the Great Tit will sing at a higher pitch to ensure that its mating calls are heard over the higher noise levels found in the urban environment.

2.1.5 Impulse Noise and Sonic Booms

Animal models have been widely used to study the effects of noise on the auditory mechanism and several of these[152, 153] have shown that the cochlea is capable of developing a resistance to noise induced threshold shift (TS) that is dependent upon its previous exposure history and on the timing schedule of a repeated exposure. However, in contrast, others[154] have not shown any evidence of a TS recovery. More recently[155], using the chinchilla as the animal model and exposing them to 6-hour daily exposures of 107, 113, 119 or 125 dB peak SPL impacts presented 1/s over a 20 day period, threshold measurements at the beginning and end of each exposure period showed that up to 30 dB resistance to TS could be developed over the first 5 days of the exposure. The higher level intermittent exposures tended to produce less permanent threshold shift (PTS) than uninterrupted equivalent energy exposures. The conclusion that was drawn was that there are peripheral cochlear mechanisms which effectively cause the auditory system to develop a resistance to TS with repeated exposures to impact noise, with the consequence that there is reduced PTS and reduced sensory cell loss.

However, although the animal studies suggest the auditory system incorporates inherent mechanisms that have the ability to reduce the potential harm of exposure to abnormal noise levels, it is important to recognise that the noise exposure circumstances used within the laboratory do not reflect the type of exposures that will be experienced in the wild. Nor do they take account of the complex interactions between animals and their predator-prey relationships in their natural habitats. Therefore, the results and conclusions from laboratory based animal models should not be applied directly to wildlife situations without further regard to the various behavioural factors considered by this research.

In a review of animal responses to sonic booms[156], it was concluded that animal reactions vary from boom to boom and are not predictable. Reactions differed according to the species involved, whether the animal was alone and sometimes whether there had been previous exposure. Reactions reported included occasional trampling, moving, raising head, stampeding, jumping and running; with birds occasionally running, flying or crowding. Similar reactions were also observed in response to low-level subsonic aircraft, helicopters, barking dogs, blown paper and sudden noises.

The reactions of farm mink to sonic booms has been studied in considerable detail and although specific responses may be elicited, for example female mink with kits may be alerted, pause in activity and look for the source of the noise; sleeping females may awaken; mating pairs may show momentary alertness but otherwise no disturbance; - no wounding, killing, carrying, or burying of kits in nests was observed in response to sonic booms[157]. In fact, in one study, the reactions of mink to barking dogs, truck noises and mine blasting were similar to the reactions to sonic booms. Other studies showed no change in milk production of a dairy herd[158,159], and no effect on eggs being hatched in a commercial hatchery[160]. Observations of wild deer, reindeer and some zoo animals likewise revealed no or only minimal and momentary reaction to sonic booms, such as raising the head, pricking the ears and scenting the air. The case of the mass hatching failure of eggs of a colony of 50,000 pairs of sooty terns has already been mentioned, although only circumstantial evidence existed at the time that sonic booms from low-level supersonic flights were the cause of indirect physical damage to the eggs. As mentioned earlier, more recent evidence has shown that sonic boom overpressures do not cause direct damage to bird eggs. Another study relating to eggs of domestic chickens[161] has reached the same conclusion – for example, exposure of

252 fertile eggs to simulated sonic booms resulted in no eggs cracking due to exposure and all chicks hatching normally. Resonant frequencies of chick eggs were quoted as 468-1036 Hz and quail eggs as 1274-1475 Hz.

In a further study[108] of eight ponies, two open cows (breeding cows that have not yet conceived), six cows with calves, and twenty-four steers, their eating patterns were monitored for 5 days before exposure, during exposure, and for 5 days after exposure to simulated sonic booms of approximately 200 N/m^2. All animals clearly showed a startle response after each boom, however, within 1 minute after the response, the animals returned to the pre-boom behavioural activity comparable to that in the baseline observations. The eating patterns and feed intake after exposure were likewise the same as during the baseline observations. In fact, less overt reactions to later booms suggest a degree of habituation. Most importantly, none of the booms elicited a state of continual arousal or general panic in any of the animals.

In a study where 120 mink were exposed to simulated sonic booms ranging from 2.0 to 0.5 psf[162] (pounds/square foot), the litters of mink exposed to the booms were actually larger than those of mink not exposed. No racing, squealing or other signs of panic were observed, and females showed little or no response to exposure during breeding, birth of kits, or whelping.

Dairy cattle studied in the vicinity of Edwards Air Force Base (California) showed few abnormal behavioural reactions following exposure to sonic booms[158], though they had been exposed to sonic booms for several years and, therefore, may have become habituated to them. Nevertheless, habituation itself indicates no adverse long term effects on this species.

Six pairs of bald eagles were observed[163] to establish their responses to various events associated with human activity having the potential to cause disturbance. Overall, the highest frequencies of response were associated with the presence of anglers, cars and gunshots. The birds showed a far greater response to gunshot (76%) than artillery noise (0%). The inference is that the birds, being close to military bases, had habituated to more distant artillery noise but that light gunshots often represented a sudden loud noise in the immediate vicinity, which an animal may be able to link with past experiences. Other studies in response to gunshots and sonic booms[164] produced responses of 52% and 63% respectively, i.e. in this case the more distant sonic boom elicited greater reaction than gunshots. Exposure to weapons-testing impulsive noise ranging from 80-129 dBPeak resulted in 'no activity' from bald eagles for approximately 93% of the time[165]. Although the 'no activity' response reduced to 73% at roosting sites, the greatest activity was only 'head turning' and there was no significant difference in nesting success between exposed and control sites.

An animal's ability to detect the proximity of a noise source, and hence the need for and type of response, is achieved using various acoustic characteristics such as the rise time, frequency content and acuity of signal. Sonic booms, heavy artillery noise and light gunfire all comprise elements of these factors though generally with the rise time and low frequency content decreasing from sonic booms through heavy artillery to light gunfire, and signal acuity increasing. Due to the impulsive nature of the sound there will not be the same opportunity for animals to gather information relating to the possible approach of the noise source (i.e. its threat potential) using variations to the noise level and frequency content over a period of time. As a consequence, impulsive noises are likely to generate either an immediate response or little response at all, which may explain why the type of response may vary from one study to another notwithstanding that other factors such as individual sensitivity or habituation will also play a part.

Wild turkey hens (*Meleagris gallapavo*), whilst incubating, displayed a few seconds of head alert response to real and simulated sonic booms but were not flushed off their nests and there was no change to brood productivity. In a study of 20 brood groups exposed to sonic booms[166] no hen abandoned her poults, nor did they scatter, and bobwhite quail (*Colinus virginianus*) showed no change to their hatching success. In the case of nesting peregrine falcons and other raptors exposed to low level jet noise and sonic booms[167], birds were noticeably alarmed (noise levels ranged from 82-114 dB(A)), however, no significant change in heart rate was detected nor was there any reproductive failure.

In response to the planned flight testing of the USAF's fighter, the F-22, over desert areas, studies were undertaken into the behavioural and physiological effects of noise and sonic booms on the Desert Tortoise, *Gopherus agassizii*. The tortoise's average hearing threshold was found to be 34 dB at 250 Hz (the most sensitive frequency), and no TTS was found after exposures to 20 subsonic overflights over a 40 minute period (levels ranging from 95 to 114 dB SEL) or to simulated booms of 2-6 pound/ft^2 (psf). However, TTS was observed for over 45 minutes after being exposed to simulated sonic booms at 6-10 psf[168].

Interestingly, tortoises did not exhibit startle responses (including urination or defecation) following any aircraft noise event, although they did exhibit startle responses when touched. No significant changes to heart rate or activity were observed in response to sonic booms, although naïve tortoises, i.e. those not previously exposed to this type of noise, were found to exhibit nearly an 8% decrease in heart rate for about an hour after 45 minutes of subsonic aircraft overflight noise. This physiological response is consistent with the worst behavioural response observed, which was the animal 'freezing' for a period of up to 113 minutes after exposure to subsonic aircraft noise[169]. The study data indicated that the freezing response resulted in a reduction of energy consumption, and the overall conclusion was that the F-22 would not cause any acute effects although chronic effects could not be ruled out. Clearly, in cases such as this, it is important to ascertain that the relatively minor behavioural and physiological effects do not have more serious effects that might not be immediately obvious. For example, as with similar responses in the lizard, respiration rates and thermo-regulation changes may be important, as will any implications with respect to loss of time spent feeding or the need for protection against predators.

When a sonic boom sweeps an expanse of water, only a small fraction of the sound energy will penetrate the water, as is also the case with noise from aircraft or helicopters flying over water. As a consequence, only the upper layer of the water is affected by noise. Tests undertaken by the ICAO Sonic Boom Committee[170,171] concluded that typical sonic booms are not likely to harm aquatic life. Further work undertaken by the US Bureau of Sport Fisheries and Wildlife[172] on the effect of sonic booms on fish and fish eggs showed no mortality difference between exposed and control groups of trout and salmon.

2.1.6 Author's observations of impulsive noise effects on horses

I undertook noise measurements of impulsive noise from plastic explosive detonations at a military training college during March 2004. An interesting feature of the site was the presence of the college's horse riding stables and paddocks that were located adjacent to the range, and noise measurements were undertaken at locations representative of the nearest and furthest exposed paddocks within which horses were grazing. Noise levels emanated from either the detonation of up to 1,000g charges of PE4 explosive inside a concrete containment building or up to 460g charges strung above a concrete pad in the open, at distances of approximately 36m and 117m respectively from the paddocks.

Unweighted peak and L_{max} noise levels were recorded using Bruel & Kjaer 2260 and Larson Davis 820 and 824 sound level meters that were calibrated against a reference signal of 94 dB at 1,000Hz. Weather conditions were dry, sunny but cold with a light breeze blowing towards the paddocks, and free-field measurements were recorded at a height of 1.5m above ground level. Ground conditions between the explosions and the monitoring points and the paddocks were soft grassland.

The L_{peak} noise levels experienced by the horses ranged from 128 to 142 dB and the L_{max} from 99 to 113 dB. The highest values occurred at the closest paddock fence during detonation of the highest charge weights, and the lower values at the furthest boundary with a smaller charge weight of 230g. During the survey a total of 22 charges were detonated over a total period of 2½ hours, with periods of between 30 seconds to 15 minutes between successive explosions.

For each explosion, the horses exhibited some degree of startle response which ranged from cessation of grazing, raising of head with ears pricked, to a short period of movement or running, which typically only involved 5 to 6 paces. After these responses, the horses remained alert for a few seconds but then returned to their activity prior to the noise event, i.e. grazing. One horse did exhibit longer periods of running following the explosions, however, the same animal also showed running behaviour during the longer periods of background noise between explosions, which suggests that the impulsive noise may not have been a direct cause of this behaviour.

The survey was not the first occasion that the horses had experienced the impulsive noises - explosions at the site occur on a regular basis for training and experimental purposes. As a consequence, the horses would have experienced similar noise levels on numerous other occasions throughout the periods that each horse had been stabled at the site, i.e. over periods of several years. Therefore, each animal will have habituated to the noise to varying degrees, which is likely to be dependent on the nervous state of individual animals, i.e. nervous animals are likely to show a greater response in terms of the amount of running or the time that it remains in a state of alert. The study needs to expose naive horses, i.e. those not previously exposed to the source, to the same peak noise levels in order to establish whether the responses of naive animals are significantly different and capable of causing either undue physiological stress or harm due to physical collision etc., and to establish the number of exposures required until the response stabilises at its minimum. The latter could be achieved by filming each horse to subsequently count the number of steps taken between the initial startle response until the animal returns to normal grazing, and to repeat this over successive exposures to plot the rate of change to the response of physical movement. The amount of physical movement is a measure of disturbance and energy consumption.

Nevertheless, the current observations show that, following habituation, very high impulsive noise levels that would potentially be capable of causing extreme startle responses only lead to slight and very short-term behavioural responses in the horse even after repeated high exposures over several hours. In contrast, a personal communication from the range officer indicated that the stable operators/horse owners did make specific complaint in relation to the disturbance caused to the horses during occasions when fireworks are set off on the range. Another personal communication from a noise colleague similarly told of adverse responses (including physical damage to frightened animals) from horses exposed to firework noise, but not from exposure to amplified music at the event that preceded the concluding firework display. It would seem that the greater variation of sounds associated with fireworks, rather than the absolute peak noise level, is capable of causing greater disturbance to horses, which is possibly similar to the situation found for many animals in response to helicopter noise as discussed later. Further work is required to establish the components within firework noises that cause disturbance and fright compared to other noise sources.

2.1.7 Fixed Wing Aircraft

During a four year study of over 112 peregrine falcon nests exposed to at least 258 jet overflights at altitudes below 400m, 111 overflights registered noise levels of at least 85 dB(A) but no females responded by taking flight and only eight males reacted in this way[173].

On a USA gunnery range exposed to low altitude overflights of F-15, F-16 and A-10 aircraft at rates greater than 70 flights/day and sound levels often exceeding 100 dB(A), the effects of aircraft noise on predator-prey population levels of the kit fox (*Vulpes macrotis*) and the kangaroo rat (*Dipodomys* spp.) have been studied[174]. A higher density of foxes and lower density of kangaroo rats were found in the areas exposed to aircraft noise but no significant conclusions were reached as it was felt that subtle differences in vegetation and rainfall between the control and exposed areas could also explain the differences. This highlights the difficulties in knowing the actual causes between different population densities, i.e. natural or noise induced. One interesting finding from the study was that at least two pairs of the radio-tracked foxes had home ranges completely within the area most heavily used by aircraft, therefore, these individuals did not appear to be adversely affected by high noise levels. However, it will be seen from later studies into the kangaroo rat how this animal is particularly sensitive to low frequency noise, which leads to significant hearing loss. Perhaps the adverse effect of low frequency noise from low altitude military aircraft on kangaroo rats causes this animal to fall prey to the fox more easily, hence allowing the fox to predominate and live successfully within exposed areas.

A useful feature of the above study is that noise events were quantified and provide a measure of the types of noise impacts likely to be encountered as a consequence of low-altitude flying. During a total survey period of 13,911 hours, pre-set noise thresholds (70-80 dB) were exceeded 21,780 times, i.e. there were an average of 1.57 events per hour. Average daily events ranged from 0 on weekends to 167 events/day during intensive training periods, with events averaging 15 seconds in duration. At the most intensely exposed sites under the flightpaths, over 40% of events exceeded 100 dB. In the absence of aircraft flights the average hourly L_{Aeq} noise levels ranged from 30-40 dB, and daytime overflights raised these levels by approximately 30 dB to 58-67 dB.

Night-time overflights were less common and raised the L_{Aeq} by 10-15 dB to an average of 43-46 dB.

The effects of low-level sub-sonic overflights by the same aircraft (A-10, F-15 and F-16) have also been studied in regard to the reactions of Alaskan caribou[175,176]. In the first study, the mean slant distance was 756m and the estimated mean SEL for the caribou was 98 dB(A). Approximately 50% of the caribou showed some overt behavioural reaction to overflights, but only 13% of the overflights caused animals to move. Analysis of the data showed there to be no relationship between SEL and the duration of reactions, nor to SEL and the distance moved. Activity budgets were also compared between exposed and control caribou, and although there were no differences evident in late winter, during post-calving and the insect season (often a period of stress and annoyance to animals) overflown animals spent less time lying and more time either feeding (post calving) or walking (insect season). Females with newborn calves appeared to be less tolerant of aircraft disturbance than were caribou during other times of the year, and the daily movement data suggested caribou with newborn calves were moving away from disturbed areas, which would involve extra energy expenditure for both females and young.

Similar findings were found from the second survey. The mean altitude of 161 overflights was 175m, and the estimated mean A-weighted SEL for the caribou during all overflights was 98.5 dB(A) (maximum 122 dB(A)). Approximately 76% of the groups under observation during overflights showed some degree of overt behavioural reaction to the aircraft, but only 30% of the overflights caused the animals to move and their mean displacement only amounted to 25m. The overall finding was that caribou interrupted their activity for a brief time (mean duration of reaction to evaluate the disturbance was 20 seconds) but they then resumed an undisturbed activity (e.g. feeding).

Visual observations of low-level (30m AGL) jet overpasses of caribou indicated an initial startle response but otherwise only brief overt reactions[177]. Using satellite-tracked radio-collars on the caribou, which provided details of daily locations plus indications of physical activity and movement, five animals were deliberately exposed to low-level overflights whilst five others were avoided during training exercises and served as controls. The records of monitored activity levels during the year of highest noise exposure showed that caribou exposed more often to low-level overflights were significantly more active, suggesting a possible threshold effect. Such a response could clearly have an important part to play in terms of energy expenditure and feeding, especially if the animal exposed is weakened due to illness or poor habitat/feeding conditions.

The study's most important finding was that the survival of a female's calf was negatively correlated to the level of exposure to low-level flying. The relationship was significant only during the calving and immediate post-calving periods, and also during the summer periods of insect harassment, when at such times calves would be most sensitive to stress. It is hard to say to what extent the absolute noise levels caused by the overflights, or the rate of change of noise, contribute to the level of stress compared to the presence of a fast moving and large threatening object. Another study of the effects of low-flying jet aircraft[178] showed that caribou responded to increasing daily sound exposure with increased movement, which incurred energy costs and increased metabolic rate. However, the effects were calculated to be small and there was no consequent effect on fecundity or herd productivity.

Although osprey nests in the training areas of Labrador and northern Quebec have been protected since 1991 from noise from low-flying aircraft by an exclusion zone of 2.5 nautical miles radius, controlled low-level passes of CF18 jet aircraft were studied in 1995[179]. The aircraft passed active nests at distances ranging from the exclusion distance of 2.5 nautical miles down to directly overhead at speeds of 400-440 knots. The maximum noise levels varied from 52-101 dB, with rapid onset rates of 26 dB/second, yet no significant difference in nesting behaviour was observed to result from the different overflight distances, noise levels or nesting periods during 139 overflights. Nesting behaviour was similar to that in control sites, and, with the exception of nestlings crouching low in the nest, no reactions akin to agitation or startle were observed despite the rapid onset rates. In fact, behaviour such as agitation, temporary nest abandonment and other extreme reactions that might affect nesting success was only observed to arise with the presence of slower fixed-wing aircraft, other osprey or raptors entering territories, and nearby observers.

Further surveys were undertaken in 1996[180] and again, no differences in behaviour were observed between experimental and control sites. The osprey exhibited no overt reactions as a result of low-level jet overflights apart from adults showing alertness and occasional adjustments in incubation posture. They appeared to perceive the approach of an aircraft before it was audible to the observers, and this response has been observed in other species in other situations of noise exposure. This initial response behaviour has been described as the orienting response and is often accompanied by increased heart rate[181], which places the animal in a state of 'increased readiness'. The overall conclusion of the surveys was that visual aspects of the events, i.e. the speed of the aircraft rather than the noise level or its duration, may act as the greater stimulus on the osprey. Other factors such as weather conditions and food supply were also identified as having greater influence on osprey productivity and may mask more subtle effects associated with the low-flying aircraft.

In contrast to the above findings, a survey that looked at both simulated acoustic stimuli (recordings of Kiowa helicopter operations, a military equivalent of the Bell Jetranger) and visual stimuli (towed shapes comprising wings and fuselage) concluded that the acoustic component of aircraft overflights near sea bird colonies may be far more important in generating behavioural responses than visual components[182]. A response to visual stimuli was observed but this was much less than the acoustic response. This difference in response may simply illustrate how different responses arise between different species, in this case the species being observed was the Crested Tern, or it may reflect the differences that can arise between real and simulated exposures. An earlier study by the same author[181] using acoustic stimuli simulating overflights by a fixed-wing DHC-2 beaver float plane indicated that the greatest responses of preparing for flight in the Crested Tern only occurred when noise exposures were greater than 85 dB(A).

The low altitude flying of a further eight types of aircraft were studied with respect to their potential influence on productivity, reproduction and behaviour of seven domestic animal species – horse, cattle, pig, poultry, turkey, mink and dog[183]. The aircraft types were five fixed wing aircraft (Fiat G91, F104 g (Starfighter), F4 f (Phantom), ALPHA jet and A10 (Warthog)) and three helicopters (Alouette II, BO105 and Bell UH1D). During the overflights of a group of horses in a large paddock, the animals showed very intensive flight reactions along the fences or random movements within the paddock, especially when the aircraft could be seen approaching. The fences were never broken or passed, but occasional biting or biting-threats as well as kicking or kicking-threats were observed, and the visible excitement did not last for longer than 2 minutes.

In another study of pregnant mares exposed to simulated F-4 aircraft noise[184] heard over 47 sec with sound intensity increasing at 55 dB/sec to a maximum of 115 dB, all delivered live, normal foals. Heart rate increased during periods of noise but habituation was observed and the increase declined with successive exposures

In contrast to the horses, a group of cattle showed some general unquietness but no panic flight movements were observed; a second group moved as a unified group, which resulted in animals at the periphery being pushed against the fences. After departure of the aircraft, the cattle continued to show orientation behaviour, in particular, eye contact being maintained with the observers. This suggests the animals remained unsettled for periods after the exposure, which indicates longer term effects on the animals endocrine system. In the case of a group of cattle mostly tied within a stable, the fixed animals were strongly excited by the low level overflights of fixed-wing aircraft. Even two and a half hours after the overflights, three of twenty animals had not calmed down.

The only sign of irritation during the overflying of pigs (pregnant sows in stables and open pasture) was some intensified wagging of tails, and even when 'chased' by helicopters at a height of only 5m the pigs exhibited only slow trotting action for brief periods. 5-7 day old chicks inside light shelters climbed on top of each other when overflown by F4 f Phantoms, though this phenomenon diminished over three days of overflying. 3-5 week old chickens showed only orientation behaviour and undirected locomotions, whereas laying hens showed orientation behaviour on the first two days only, with diminishing reactions and even sleeping on the third day. However, overflights by a hovering BO105 helicopter tended to elicit greater response.

Similar reactions to jet aircraft and helicopter overflights were exhibited by mink in that straight ahead overflights by both fixed-wing aircraft and also helicopters caused lesser responses than hovering helicopters that produced quite short but stronger responses. Helicopter types did not affect the response but different sensitivities were observed in different species of mink, e.g. 'Saphir' females were found to be more sensitive to overflights than 'Black cross' females. In contrast, in the case of adult watchdogs, the study resulted in the strongest reaction to fixed-wing aircraft.

Pigs exposed to recorded jet and propeller aircraft noise of 120-135 dB daily from 0600 to 1800 hours, and throughout the period from weaning to slaughter at 200 pounds body weight, showed no significant differences in feeding or weight gain from pigs unexposed to the noise[185]. Dairy cattle likewise regularly exposed to jet aircraft noise due to their farm locations within 3 miles of air force bases (13% of the herds were within 1 mile of the end of an active runway) similarly showed no difference to milk production.

The key findings of the above studies on domestic animals are that there are species-specific, breed-specific and individual differences in type and intensity of behavioural reactions; there are differences in response due to overflight characteristics such as the level and tonal quality of noise and whether the aircraft pass directly over or hover; and there are indications that animals adapt to noise without any long-term sensitisation. It is possible that the different reactions to passing and hovering aircraft might involve optical as well as auditory cues or the animal's ability to relate rate of change of noise level to the proximity of the source, i.e. sources that pass quickly and move away from the animal are less likely to cause prolonged responses compared to those that remain within close proximity.

In America, claims have been made against the US Air Force for serious effects on domestic animals due to aircraft overflights, including breakage of chicken eggs and reduced hatchability; lowered productivity; stampeding cattle; abortions of pregnant animals; cannibalisation of early young; and reduction of milk production in dairy cattle. A number of studies have been undertaken to evaluate the claims and it would appear that these largely confirm the findings of other studies. For example, a study of dairy cows[186] showed no signs of behavioural reaction, nor was there a change in milk yield due to aircraft noise disturbance. In another study designed to examine the effects of aircraft noise on pregnancy, behaviour, habituation and cardiac function of pregnant mares[187], all exposed mares delivered live normal foals without assistance. However, exposed mares did show significant differences in the level of anxiety and movement compared to control animals, and their heart rates increased during noise events, but no injuries occurred and no ectopic arrhythmias were observed. Overall, some behavioural and physiological adaptation to the noise events was observed.

Turkeys were found to habituate very rapidly to aircraft overflights, and turkeys exposed to chronic worst-case aircraft overflight noise were found to grow at the same rate as control animals although they had some behavioural differences and were found to be more difficult to handle[188]. The behavioural problems suggest that noise had some adverse effects even though the growth rates remained normal. Of the noise units, SEL is reported as the most useful predictor responses. Broad breasted bronze turkeys exposed to recordings of low-level jet aircraft producing 110-135 dB for 4 minutes during the third day of brooding, typically ceased brooding but then soon resumed it, and there was no subsequent decrease in egg laying[189]. Poultry have likewise been exposed to recordings of aircraft flyover noise at 80 to 115 dB at 300 to 600 Hz, played daily and every third night from the beginning of the hens brooding until the chicks were 9 weeks old[190]. The result was no difference in weight gain, feeding efficiency, meat tenderness or yield, or mortality between exposed and control chicks.

The effects of both simulated and actual low-altitude jet aircraft noise have been studied on the heart rate of captive desert mule deer (*Odoncoileus hemionus crooki*) and mountain sheep (*Ovis canadensis mexicana*)[191]. Flights were due to F-16 aircraft and produced noise levels between 92-112 dB in the vicinity of penned animals. All animals became habituated to sounds of low-altitude aircraft, and although heart rates increased during overflights they returned to resting rates in less than 2 minutes. Heart rate increased above normal in 21 of 242 overflights but returned to normal within 2 minutes. The study concluded that F-16 aircraft flying over mountain sheep did not create increases in heart rate that are detrimental to the animals.

Similar tests were undertaken with 12 Desert Bighorn Sheep[192] that were firstly located within an enclosure for one year without any planned aircraft overflights. During a second year the same animals were exposed to F-16 overflights whilst the animals' heart rates and behaviours, linked to habitat and vegetation usage, were monitored as they were for the control year. The results were similar for both the control and the test years, with the conclusion that the aircraft overflights did not have any adverse affect on the population. In fact, each of the 6 ewes in the study had lambs each spring of the study.

Although long-term adverse effects are not indicated by the above studies, one study[193] did acknowledge that since the age at which wild sheep attain sexual maturity is dependent on their nutritional state, energy losses as a result of avoidance reactions from low-flying aircraft may affect their reproductive process. This could have long-term implications that may not always be evident from short-term observations of animal communities.

With the farming of ratites such as the ostrich (*Struthio camelus*), emu (*Dromaius novaehollandiae*) and greater rhea (*Rhea americana*), the acknowledged nervous behaviour of these species has also lead to studies into the effects of low-flying aircraft noise. The greatest cause of mortality in farm-raised ratites is traumatic injuries resulting from panic movements, predator attacks and fights, therefore, it is important to know the extent to which aircraft movements and other noisy events might affect the social behaviour of the stock. Data from compensation claims and complaints ensuing from the overflight of more than 2,000 birds in the US during 1993 and 1994 showed 19 fatalities or a loss rate of 1% of exposed birds[194]. In addition, 7 cases of breeding declines and 2 cases of stress were reported. Further data relating to the responses of more than 3352 birds was available from returned questionnaires sent to farmers, and these provided evidence of 3 mortalities at two farms, a leg injury at one, and minor injuries at two others, i.e. a loss rate of 0.2% including injuries.

Following ambient noise measurements at a number of farms it was established that the ratites were exposed to many other noise sources besides the planned experimental overflights. Thunder was the most intense, with maximum levels being 120-130 dB (peak SPL); farm machinery also produced high noise levels ranging from 92-104 dB ASEL. Overall, ratites were exposed to a broad range of other noise sources including light aircraft, trains, shotgun blasts, lorry traffic, jet aircraft near a major airport, and noise from cattle. Average L_{Aeq} noise levels at the farms ranged from 47-70 dB, with levels being below 70 dB(A) for 95% or more of the monitoring period. In comparison to the above noise sources, high-amplitude F-16 overflights produced ASEL levels of 96.5 to 110.6 dB, and levels across the animal pens varied by less than 10 dB and often by less than 3 dB. When simulated aircraft noise was used, it was found that much greater variation of noise levels (up to 20 dB) occurred across the pen.

Ratites tend to react to noise disturbances by way of controlled species-typical aggressive and defensive behaviours. These are likely to include 'tall alerting', running (usually to congregate), orienting towards the incoming sound (even when an aircraft was not visible), mild aggressive gestures, evasive movements designed to throw off predators, and flock running, which involves running in a flock along the borders of the pen at high speed. At no time during the surveys did ratites panic in response to overflights, i.e. blind running and collision with fences was not observed. However, flock running in emus was aroused once by a UH-1 helicopter at a range greater than 3,000 ft and also in ostriches by a UH-60A helicopter, but the greatest incidence of risky behaviours was highest when aircraft were directly overhead and at low altitudes.

Key conclusions from the study on ratites were that simulated overflight noise did not model the situation as well as real exposures; the most traumatic injuries occurred when individual birds made mistakes in their movements close to other birds rather than a mass panic; and flock running was observed in response to helicopters at ranges as great as 1 km.

A further study[195] sought to analyse the apparent contradiction that exists between the long-term animal studies, which it suggested show very little direct impact on animals due to low-flying military aircraft, and the relatively high level of claims against the US Air Force for compensation due to damage caused by noise. Claims spanning a period of 32 years were reviewed and the main types of loss resulted from panic caused in naive animals, and reproductive failures or failure to gain weight. The study reported that over 62% of the compensation costs related to a single claim when animals stampeded and escaped, and that claims are remarkably uncommon when compared against the actual numbers of logged flight miles; the overall conclusion was that the economic loss to the community from this type of activity is small.

2.1.8 Helicopters

Many studies have been undertaken into the responses of different animal species to exposure to noise from helicopters and fixed wing aircraft but unfortunately the findings are as diverse as the animals and situations being studied. A major difficulty is that many of the factors that can influence the way in which an animal responds to a stimulus are not fully considered or documented within each study - even obvious matters such as noise levels are not always recorded. To give an indication of the problem, the range of factors that may have some influence on the noise level at the animal's position and hence the animal's reaction are listed below:

- type of aircraft (or other noise) source;
- particular acoustic characteristics associated with source;
- distance between source and animal;

- height of source above ground level (AGL);
- vehicle speed and loading (level and rate of change of noise);
- time of event relative to the animal's normal diurnal behavioural patterns;
- prior exposure;
- position of source and animal in relation to terrain, plus habitat characteristics;
- condition and activity of animal(s);
- animal group composition;
- effects of seasons and biological cycles;
- auditory and visual cues;
- position of the sun relative to the source and animal; and
- wind and other weather conditions.

Comprehensive reviews of responses of raptors (birds of prey) to helicopters have been undertaken[196] with the conclusion that helicopters tend to elicit more responses and a higher proportion of flight responses, as opposed to merely alerting, than most other stimuli. Responses also occur at greater distances than for fixed wing aircraft. Similar findings have been reported by other researchers for exposures of different animal species. From exposures of wildlife, especially waterfowl, at US Fish and Wildlife Service areas[197,198], helicopters were reported as disturbing wildlife more than fixed wing aircraft.

In a study that monitored the locomotory and other behaviour of caribou during and after military jet aircraft and helicopter overflights[199], the animals responded more strongly to the helicopter than fixed wing aircraft, which was reflected by a shorter latency response and longer and farther movements. However, although another study similarly showed that snow geese were flushed sooner in response to helicopters (Bell 206 and Hughes500) compared to fixed wing aircraft, in contrast the geese actually flew farther in response to small fixed wing aircraft[200].

Different investigators can report conflicting results on which type of aircraft produced stronger reactions as demonstrated by studies on caribou[201, 202]. Unfortunately, prior exposure of the animals to small propeller planes and the small Bell 206 helicopter is not documented.

In complete contrast, a study of the short term responses of wading birds to a propeller driven fixed wing aircraft and a Bell 47G-2 helicopter reported that the helicopter caused less disturbance than the fixed wing aircraft[203]. In all cases disturbed birds were reported as returning to their nests within 5 minutes, nevertheless, the flight of the birds would have initiated physiological reactions, energy loss, temperature changes and exposure of eggs or young to predation.

Studies of game-farm mink[204, 183] looked at the exposure to aircraft noise with and without the visible presence of the aircraft. The studies showed little response to fixed and rotary-winged (BO 105) noise in the absence of visual cues. When the noise event was coupled with a visual stimulus, i.e. the aircraft could be seen by the mink, the animals oriented towards the stimulus.

Observations of red squirrels[205] showed that they reacted more to helicopters, bulldozers that came close, and people on foot than to bulldozers at a distance, blasting, and non-tracked vehicles. The study illustrated the ability that many animals appear to have to use acoustic characteristics associated with the noise source and its noise transmission to determine the proximity of a source and hence whether 'flight' is necessary. Unfortunately, noise levels were again not quantified. Other research[206] clearly establishes that there are features associated with helicopter noise that tend to elicit responses even when the source is distant and noise levels will be correspondingly lower. Like many other researches, the work also concludes that helicopters usually elicit more vigorous behavioural responses and/or responses at a greater distance than fixed wing aircraft. Identification of precisely what features of the helicopter noise trigger the more vigorous or early responses would possibly enable other noise sources to be rated accordingly.

With regard to distance between the source and the animal, moulting arctic geese reacted strongly to noise of Bell 206 and 212 helicopters[207]. The larger 212 caused reactions at about 9 km even though the helicopters were not visible. In the case of the sea bird Brunnich's Guillemot[208], the birds sometimes responded to a helicopter at a distance of 6 km and always by a distance of 2.5 km. Both these studies demonstrate that at the distances responses occurred the animals are responding to acoustic rather than visual cues, and the latter again illustrates an animal's ability to determine the proximity of a source. The guillemot incubates its eggs by placing them on the top surface of its feet, therefore, the eggs are vulnerable to being broken if the incubating parent is disturbed. Brood mortality has been reported due to fixed wing aircraft and helicopters, however, where overflights are frequent, the birds do not normally react, which suggests habituation.

In contrast to the documented responses to helicopters at significant distances, other studies of bighorn sheep[106] showed little change in the animal's heart rate in response to humans on foot, vehicles on a road, low-flying fixed-wing aircraft, or helicopters at distances of 0.5 to 1.5 km. However, a single sheep exhibited increased heart rate (3.5 times normal) and began to run when a Bell 206 helicopter flew directly overhead at 150-200m AGL. This illustrates how for communal animals, the noise event only needs to adversely affect one animal for others to be triggered into a similar response.

In a study of black brant geese and the unplanned flyovers by eagles, helicopters and fixed wing aircraft[126], the geese oriented the head and took flight in response to aircraft (helicopters and fixed wing) at about double the distances they reacted to eagles. Using a large Bell 205 and smaller Bell 206 and Hughes 500-D, the large bell produced the largest proportion of responses, however, helicopters showed no uniform trend of probability of response with aircraft height. Earlier studies[209] likewise demonstrated that for a Fairchild-Hiller 1100 helicopter flying at a distance of about 100-150m from dall sheep in mountainous terrain, reactions were independent of whether the helicopter was above, level or below the sheep. Ewes with lambs reacted more strongly than rams.

Eleven different avian species were studied during exposure to helicopters and other aircraft and their reactions were rated on a scale of 1 (no reaction) to 4 (violent reaction/left area)[210]. Five species (Canadian and Snow Geese, Sandhill Cranes, Turkey Vultures and Great Egrets) showed no change in response with increasing helicopter noise level, but what is important is that Canadian and Snow Geese did not tolerate helicopter noise at any level. The other six species did alter their response with increasing noise level – the grebes' response increased only slightly while the response of ring-necked ducks, coots, gadwalls, purple gallinules and pintail ducks increased more strongly with increasing helicopter noise. Since the geese showed no likelihood of adapting to the helicopter noise, these birds would benefit from helicopter exclusion zones.

Reindeer were once herded by helicopter in Russia, though the practice has now discontinued due to detrimental effects on the animals. During controlled overflights of caribou using a Fairchild-Hiller 1100, stronger responses occurred during low rather than high flights[96]. Of 35 red-tailed hawk nests approached using an army UH-1 Huey (equivalent to Bell 205) 40% of birds flushed at about 40-110m[211]. In contrast, more overt responses of gyrfalcons and other arctic raptors were elicited by helicopters at 300m AGL than at 150m AGL[212, 213]. In another case, in 82% of helicopter flyovers (of unspecified type) as low as 40m, sandhill cranes in Florida remained on their eggs[143].

Low altitude flights over pregnant dairy cows did not cause them to run or injure themselves, nor was there any indication of reproductive problems[214]. However, the overflights did produce vigorous behavioural, heart rate and glucocorticoid increases. In another study, muskoxen and caribou responded more strongly to a circling helicopter (Bell 206B at<400m AGL) than to simple overflights[215].

During recreational helicopter overflights desert bighorn sheep decreased the time they spent foraging by approximately 17%[216, 217], but the magnitude of the effect and the interaction with the altitude of the sheep varied strongly according to season. Whether or not the loss of foraging time has an adverse effect will depend on the duration of the noise exposure relative to the normal foraging periods, the condition of the animal and the abundance and quality of available feed materials in the animals normal range.

A comparative study[218] into the effects of noise from helicopters (HH-60G) and chain saws on Mexican Spotted Owls (*Striz occidentalis lucida*) concluded that chain saws at comparable distances were more disturbing than helicopter overflights, and that short duration, single pass overflights had little impact beyond a protection zone of 100m. During the nesting season, owls did not flush when the SEL was <92 dB(A), and the same circumstances applied during the non-nesting season. However, since many studies identify that human presence often causes greater responses than noise, and since men will always be present when chain saws are operated, there must be some risk that the response attributed to chain saws could actually be due to human presence.

2.1.9 Artillery

An increase in the number of successful nests of Bald Eagles (*Haliaeetus leucocephalus*) has been observed by the US Army at the Aberdeen Proving Ground in Maryland[219]. Eight active nests in 1990 increased to 14 in 1995 and 24 in 1996. The influence of weapons testing was studied by observing behavioural effects before and after noise events. During a 2 second period after noise events, 92.7% of the time no change in eagle activity was observed, and 0.7% of the events caused head-turning. Similar responses were observed during winter roosting. There were also no differences between the testing ground and control sites with respect to nesting success, numbers of young per occupied territory, young/active nest, and young/successful nests. As a consequence the study concluded that bald eagles at the testing ground showed no significant behavioural reactions to weapons testing at nests or roosting sites.

The on-going effects of military training noise on the endangered red-cockaded woodpecker have been studied[220] by recording response behaviours and nesting success during and after several hundred training exercises, and comparing these to situations without noise stimuli. Very few overt responses to noise were observed and there was no significant difference in breeding success between disturbed and undisturbed sites.

Noise from .50 caliber machine gun fire and artillery simulators similarly did not significantly affect reproductive success[221].

During test firings of MLRS at OTA I observed that birds (golden plover and lapwing) that were previously feeding, resting or nesting at ground level were startled into flight as a consequence of the noise due to the initial firing of the rockets. This reaction not only placed the flying birds directly in the path of the rocket, or subsequent rockets during ripple firing, but it meant that birds ended up being much closer to the rocket noise than they would have been if they had not been startled into flight. This would have resulted in a higher noise exposure and greater threshold shift in hearing, with the possible risk of some hearing damage.

The effect of rocket noise has been monitored at the Kodiak Launch Complex in Alaska by way of pre and post-launch bird surveys[222]. Harlequin duck numbers were similar before and after launches, and rocket launches also had no noticeable effect on bald eagles nesting in the area.

2.1.10 Industry

A study in Alaska looked at the effect on waterbirds of an incremental increase in noise from the additional operation of two gas-turbine compressors at an existing oilfield facility[223]. The birds observed included two species of loon, four species of geese, Tundra Swans (*Cygnus columbianus*) and ten species of duck, with the main emphasis on nesting Canada Geese (*Branta canadensis*) and brood-rearing Brant (*Branta bernicla*). The new compressors contributed most significantly at low frequencies (31.5

and 63 Hz bands) and long term L_{Aeq} noise levels measured near the facility increased by almost 3 dB from 52.2 to 54.9 dB after addition of the compressors.

However, what was most interesting, is that analysis of the noise contours under different (long term) meteorological conditions showed that compared to the average noise level caused by the compressor operations, wind direction had the greatest influence on noise levels in the immediate vicinity of the facility. Therefore, whatever the observed effects due to the additional noise generated by the new plant, natural circumstances will generate higher noise levels at various times of the year and, one assumes, the short-term responses to noise at those times should be greater. In fact, spring weather conditions had a greater effect on both the number and success of nesting birds than did increased noise. Shifts in the distribution of Canada Goose flocks during pre-nesting indicated avoidance of sites within 500-750m of the facility. Only one other species, Spectacled Eider (*Somateria fischeri*) displayed a shift in distribution attributed to the avoidance of areas increased by noise. Noise levels within brood-rearing habitats used by Brant were found to be higher after the installation of the compressors, but no significant change was detected in the use of those areas. For other species, few changes in abundance and distribution could be attributed to increased noise due to the compressors. In another study of waterfowls affected by continuous noise from a compressor station[224], laying rates did not change at L_{eq} levels below 70 dB.

The effects of chain saws on the Mexican Spotted Owl were studied in the Lincoln National Forest as they were for helicopters[218]. During the nesting season, the owls did not flush when the $L_{Aeq\ 10\,sec}$ from the chain saw operation was <46 dB(A). For the non-nesting period, the level below which flushing did not occur was 51 dB $L_{Aeq\ 10\,sec}$. The overall conclusion was that distance was a better predictor of spotted owl response than sound level, and a separation distance of approximately 100m was proposed in order to prevent any negative impacts such as flushing. The same study looked at the effects of helicopters, and chain saws consistently produced stronger responses than helicopters at comparable distances, although I have already remarked that the presence of the human operator might have influenced responses.

Densities of grassland birds have been found to be lower within 80m of wind turbines[225], although the disturbance caused may have been as much due to physical movements of the turbines and the occasional human presence as much as noise from the turbines. Further research involving the playing of wind turbine noise in the absence of other physical factors would be required to establish whether noise itself is a cause of disturbance.

2.1.11 Marine

Underwater noise or vibration can similarly affect animals of the marine or freshwater environments. An assessment procedure for these environments will generally be of less importance to the normal planning processes that typically apply to land based developments, and the science and effects of underwater noise and vibration are a complex topic beyond the scope of this thesis. Nevertheless, data relating to underwater noise impacts has been recorded from the information reviewed for this thesis, and the information has been presented in Appendix IV.

2.2 Animal Hearing Thresholds

Many studies have shown that the application of identical levels of acoustic overstimulation applied to different species can produce contrasting physiological and anatomic responses in the different animals. Unfortunately, it is generally difficult to establish the precise reasons for the differences because the experimental conditions are very different from one experiment to another and from one species to another. The same sort of difficulties have been identified with respect to the field observations of animal responses to noise sources in that the actual noise levels and operating characteristics of the sources are not always identified.

The threshold shifts and histological alterations caused by an identical acoustic stimulus (4 and 8 kHz at levels ranging from 80 to 132 dB SPL over periods of 20 minutes) have been applied to cats, chinchilla and guinea pig, and the results measured[226]. These studies have indicated that the largest part of the interspecies differences in auditory susceptibility is due to the transmission of the acoustic stimulus from the free-field to the inner ear. This suggests that the animal form, in the shape and dimension of its pinna and ear canal, may have a great part to play in an animal's ability to perceive and respond to noise levels. A factor that can influence the degree of threshold shift and which would be largely undetectable for observers of environmental noise effects is the presence of unilateral hearing damage. Recent studies have shown that for an animal with a chronic unilateral hearing loss, a normal hearing ear has a lower than normal susceptibility to loud noise to the extent that exposure to noise exacerbates TTSs in the normal ear compared to control animals with bilaterally normal hearing[227]. This situation could lead to a greater adverse response to noise than might otherwise be expected.

However, the thrust of this research is not dependent upon detailed studies of the mechanics of animal hearing and the differences between different species. Rather, it is the actual hearing thresholds and the peak sensitivities that are important in terms of an animal's response and development of an assessment threshold and procedures.

2.2.1 Hearing Sensitivity

For reference purposes, the typical hearing range and peak auditory sensitivity of animals discussed in this chapter are presented in Table 2.1 and compared to that for man. The data can be used together with a noise source's frequency composition to identify when a species may be more at risk from exposure to noise. The information will be introduced in due course into the proposed assessment methodology formulated in Chapter 5.

Table 2.1: Ranges of Animal Hearing

Animal	Approximate Hearing Range, Hz		Peak Sensitivity, Hz
	Low	High	
Man[228]	20	20,000	2,000-4,000
Ant[229]			20,000-60,000
Noctuid moth[230]	100 1,000	100,000 240,000	50,000-70,000
Arctiid moth[231]	8,000	128,000	40,000
Nocturnal Lepidoptra[232]	5,000	100,000	15,000-40,000
Mantis[231]	2,000	100,000	32,000
Lacewing[231]	15,000	130,000	64,000
Cockroach			(detect displacement)
Scorpion			(hairs detect air movement as low as 0.02 m/s)
Locusts[233]	1,000	40,000	
Cricket[234]	3,000 8-12[658,(i)]	100,000	5,000-20,000
Bush crickets[120]	3.000	50,000 105,000[659,(ii)]	10,000-20,000
Crab			(hairs detect vibration)
Crayfish			(detect displacement 0.1 microns at 100 Hz)

Animal	Approximate Hearing Range, Hz		Peak Sensitivity, Hz
	Low	High	
Fish[235]	50	2,000	200-800
Cod[236]	2	500	20
Flatfish[237]	30	250	110-160
Lemon sole[235]	32	250	125
Salmon[238]			<380 Hz
Atlantic eel[239]		300	
Carp[240]	100	3,000	400-900
Damsel fish[241]			500
Catfish[242,243]	50	1,000	100-200
Goldfish[244]	70	4,600	600
Knifefish[245]	100	1,000	500
Aya[246]	200		
Sharks[247]	50	7,000	25-100
Frog/Toad[248]	100	3,000	
Tree frog[249]	230	3,420	
Reptiles[250]	50	2,000	
Tortoise/Turtle[251]			100-150
Desert tortoise[252]			250
Green sea turtle[253]	100	500	
Turtles[254]	20	1,000	400
Lizards[255,256]			700-2,000 400-4,000
Desert iguana[257]			900-3,000
Birds[258]	100	10,000	1,000-5,000
Spruce grouse[259]	80		
Quail[121]	500	8,000	1,500-3,000
Pigeon[110]	0.05	200	
Owls[260]	400	9,000	
Barn owl[261]	100	12,000	3,000-9,000
Tawny owl[262]			400-7,000
Long-eared owl[263]			500-8,000
Cowbird[259]		11,000	
Crow[264]	300	8,000	1,000-3,000
Canary[121]	300	8,000	4,000
Budgerigar, canary, cockatiel, starling, sparrow, zebra finch[265]	300	10,000	2,000-5,000
Mallard[266]	250	8,000	2,000
Little brown bat[250]	10,000	128,000	40,000
Fish eating bat[250]	1,000	128,000	40,000
Brown bat[267]	200 10,000	5,000 100,000	700-1,300
Macaque[228]	28	37,000	4,000
Rodents	1,000	100,000	5,000-18,000/40,000-60,000
Mouse[268]	2,000 1,000	90,000 100,000	
Rat[269]	1,000	90,000	20,000-22,000
Kangaroo rat[268]	50		
Gopher[250]	63	32,000	2,000
Treeshrew[250]	125	64,000	16,000
Hedgehog[250]	250	64,000	8,000
Weasel[270]	50	60,000	1,000-16,000
Cats[271,272,273,274,275,]	40	90,000	
Dogs[276,277]	40	50,000	
Fox[278]	20	50,000	900-14,000
Rabbit[268]		49,000	

Animal	Approximate Hearing Range, Hz		Peak Sensitivity, Hz
	Low	High	
Horse[279]	31	40,000	50-100
Cow[250]	16	40,000	8,000
Cattle[280]	16	40,000	
Sheep[281]			7,000
Wolf[282]			400-2,000
Elephant[283,284]	16 1	12,000 20,000	1,000
Killer whale[285,286]	800	70,000	
Porpoises[287,288]	1,000	100,000	
Dolphin[289]	100	90,000	20,000-75,000
Bottlenose dolphin[290]	500	36,000	
Manatee[291]	2,000	10,000	3,000
Seals and sealions[292,293]	200 150	55,000 >70,000	2,000-16,000 1,000-30,000

Note: Where various ranges are presented for an animal, these reflect different values documented in the literature either from different studies or for different species of animal.

(i) As defined by wing-flick signals during courtship that cause low-frequency air movements.

(ii) As defined by the high ultrasonic frequencies forming the dominant carrier in the calling song.

An animal's peak sensitivity, which is centred around the faintest sounds that it can hear, can be used as a reasonably good predictor of the potential for either hearing damage or adverse responses to environmental noises that comprise the same frequencies. Audiograms that display both auditory sensitivity and hearing range provide the base information in the most useful format for assessment purposes since a scheme's noise level at the animal position can be plotted against the hearing threshold data to show how far noise will extend into the animal's hearing range. The amount of incursion into an animal's hearing range will provide a measure of the degree of audibility this will engender and hence the likelihood of some form of physiological or behavioural response. If a noise level falls below the hearing threshold or is only just audible to the animal it is unlikely to generate a significant or strong response.

In order to provide some reference data I have collated various examples from published audiogram data for fish, amphibia, reptiles and mammals and the information is plotted in Figures 2.2 to 2.12. The source data for each individual audiogram is presented in Appendix V. The audiograms for fish (Figure 2.2) show a range from 50 to 4,000 Hz, with a typical peak sensitivity between 100 to 1,000 Hz, and a threshold of at least approximately 55 dB re: 1 μPa before underwater sounds become audible, with the goldfish showing the greatest sensitivity. Thresholds are similar to that for a human diver although the latter has a wider range encompassing higher frequencies. The human ear underwater is less sensitive than in air although underwater it does exhibit better sensitivity to low frequency sounds. The presence or absence of air bubbles in the ear canal also affects the hearing threshold. Air bubbles will often be trapped in the ear canal as a person dives and this causes the hearing threshold to be lowered by between 5-15 dB at all frequencies[294], probably due to the water mass's reduced load on the tympanic membrane.

Figure 2.3 shows some data available for amphibia and reptiles, which is compared to a mean threshold for man. The hearing ranges are less than for man (0 to 20,000 Hz), being approximately 100 to 5,000 Hz for the frogs and 10 to 1,000 Hz for the turtle. The hearing thresholds for frogs are higher, being approximately 9 dB re 20 μPa at 630 Hz for the bullfrog, whereas the turtle shows slightly better hearing than man at low frequencies, with a threshold of 0 dB at 200 Hz.

Figure 2.2: Fish Audiograms

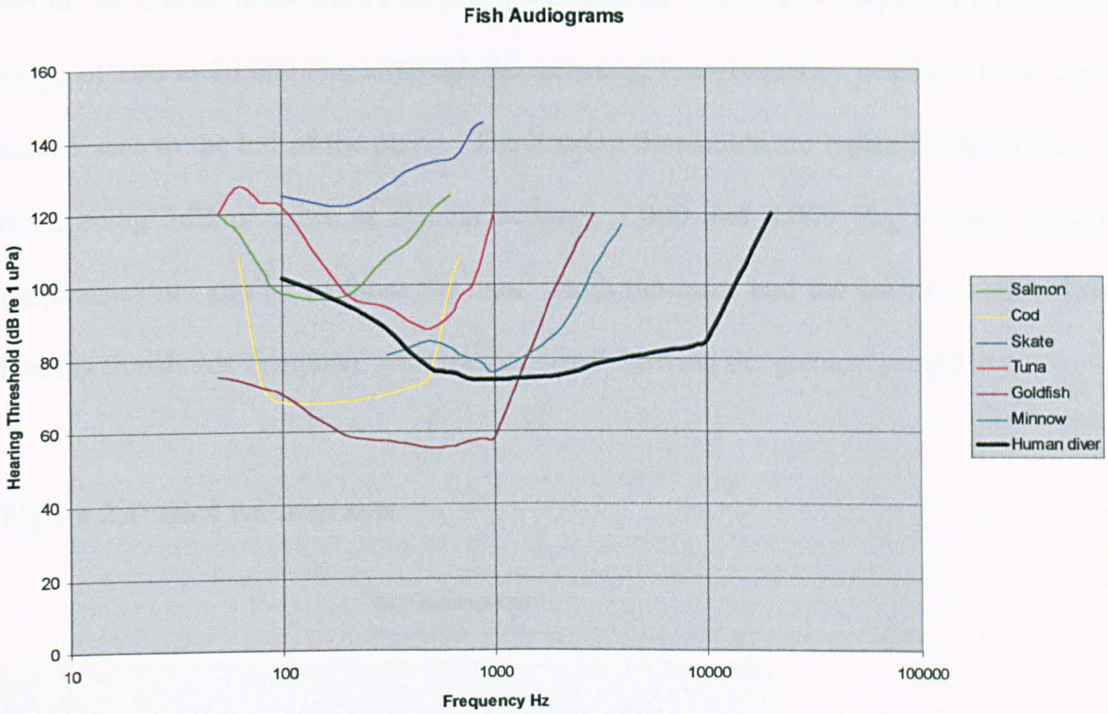
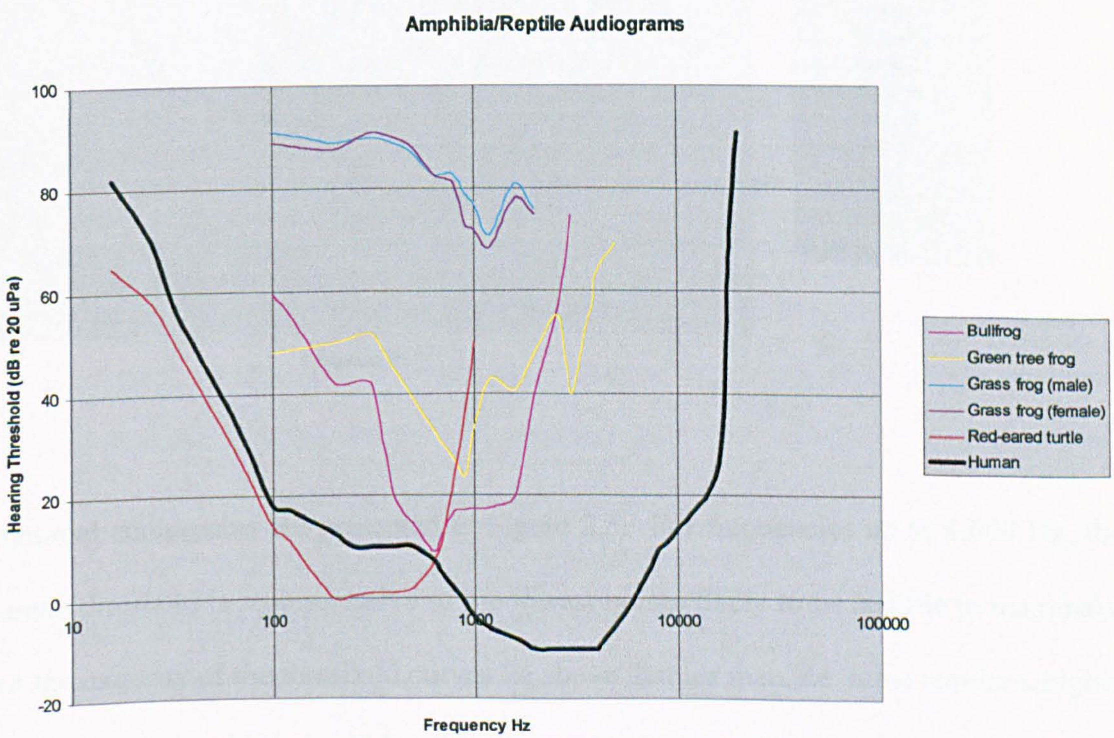
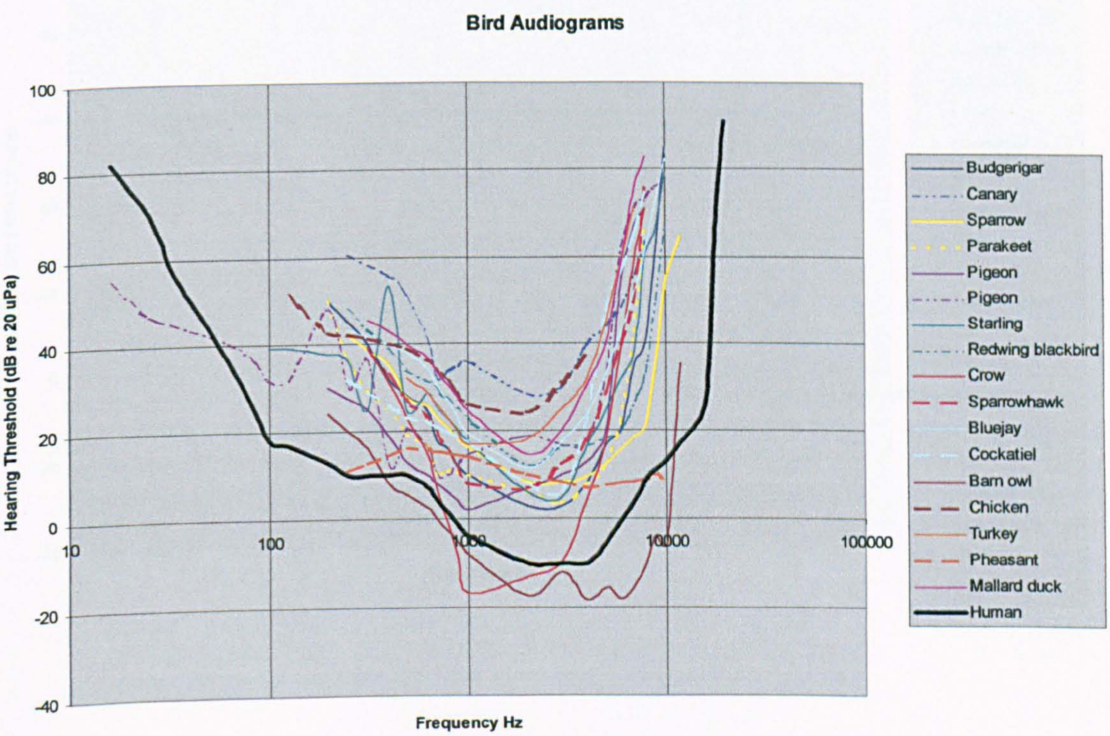


Figure 2.3: Amphibia and Reptile Audiograms



Audiograms for various birds are presented in Figure 2.4. On the whole, these lie within the human audiogram curve and demonstrate a generally slightly shorter hearing range of 100 to 10,000 Hz, although the extended low-frequency hearing of the pigeon can be seen to the left of the graph. The hearing thresholds are typically higher than for man, being 3dB or more at sounds between 1,000 and 4,000 Hz, but the sensitive frequencies are similar to those for man. Both the crow and the barn owl show lower hearing thresholds than man, with the barn owl showing the greatest sensitivity.

Figure 2.4: Bird Audiograms



Mammal audiograms are presented in Figure 2.5. For frequencies up to 4,000 Hz, the human threshold is representative of the lowest noises likely to be audible to mammals, but the majority of the threshold curves lie above that for man, i.e. most require a higher noise level before being audible. The chimpanzee, cat and raccoon show very similar thresholds to man over the above frequency range. What is very clear from the audiograms in Figure 2.5 is that many mammals have much better high frequency hearing than man, with ranges extending to between 40,000 to 100,000 Hz. Figures 2.6 and 2.7 show the same information but split for clarity between respectively large and small mammals. It is evident that all of the 'small' mammals sampled show better high frequency hearing than man, and most of the 'large' mammals show the same trend.

Figure 2.5: Mammal Audiograms

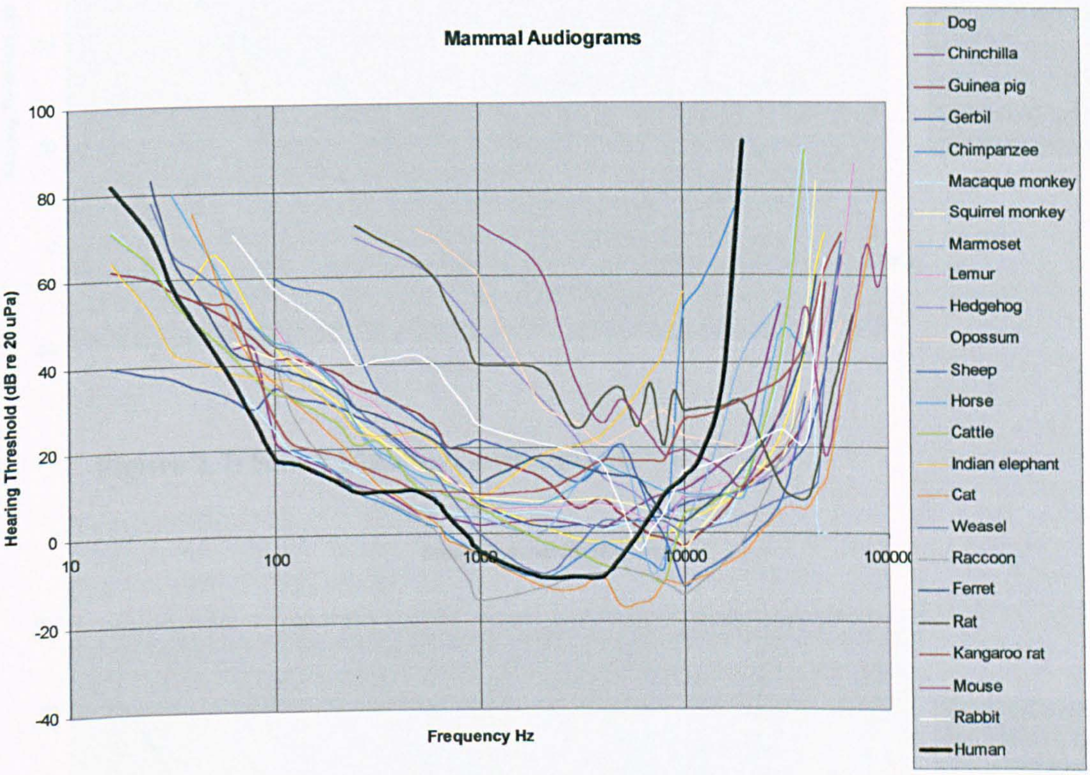


Figure 2.6: Large Mammal Audiograms

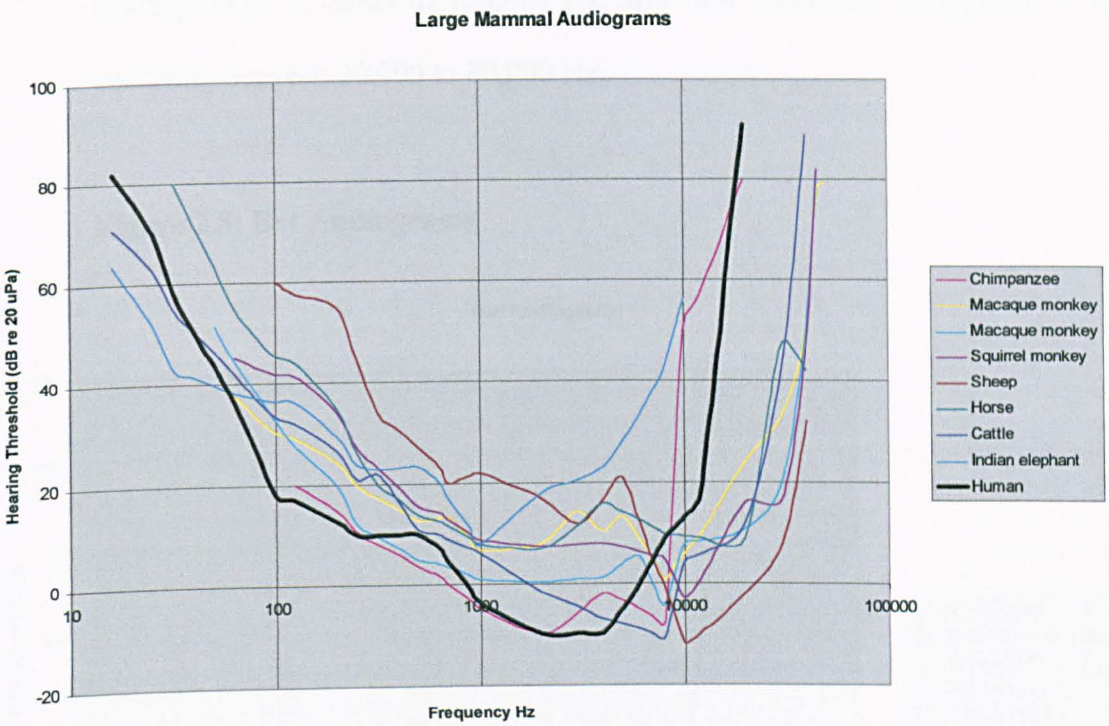
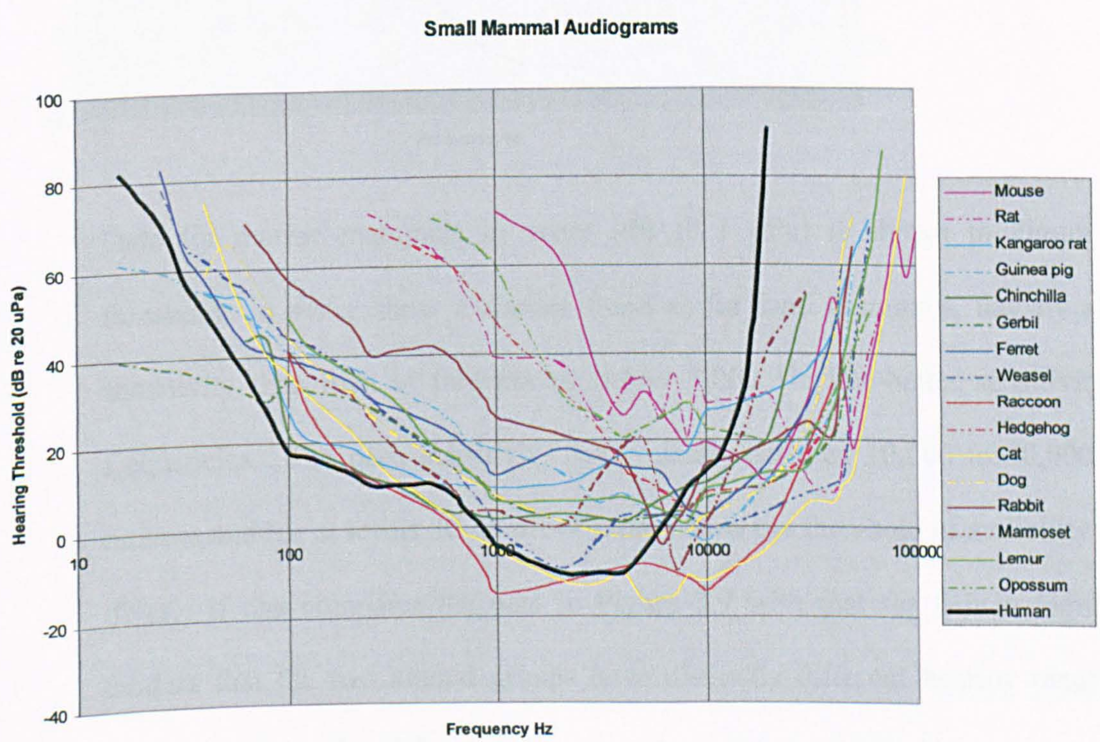
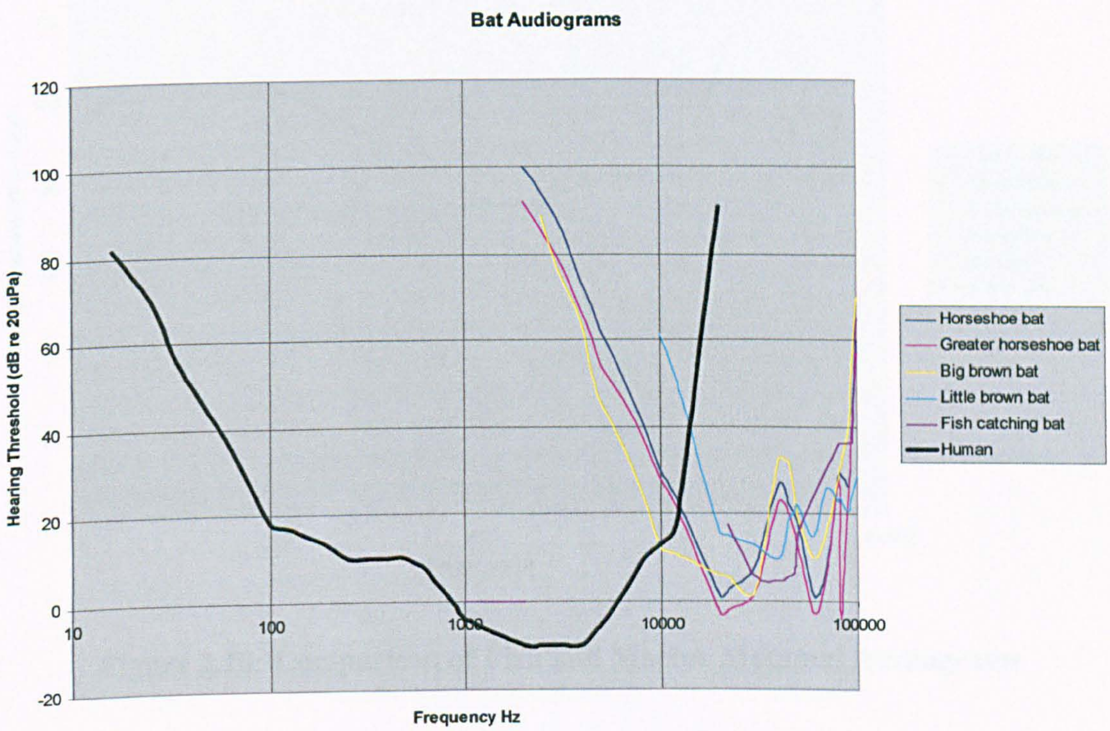


Figure 2.7: Small Mammal Audiograms



For clarity, the examples for bats are displayed separately from the other mammals because the data is distinctly different. The threshold curves in Figure 2.8 show a hearing range of 2,000 to 100,000 Hz, with low thresholds of typically 0 dB or less occurring between 20,000 to 80,000 Hz.

Figure 2.8: Bat Audiograms



Data for marine mammals in water (dB re 1 μPa) is shown in Figure 2.9. The thresholds in water show a similar trend as for land mammals, namely slightly less sensitivity than man at frequencies below 1,000 Hz but better sensitivity at higher frequencies. The peak sensitivity lies typically between 10,000 to 50,000 Hz, where noise is audible at levels 20-40 dB or more below the threshold of audibility of a human diver. If one compares the data in Figure 2.9 with that for fish in Figure 2.2, it is evident that the two animal groups have distinctly different hearing ranges, with the peak sensitivity for fish covering the range 100 to 1,000 Hz and that for marine mammals extending from 10,000 to 50,000 Hz. This comparison is presented in Figure 2.10.

Figure 2.9: Marine Mammal Audiograms (in water)

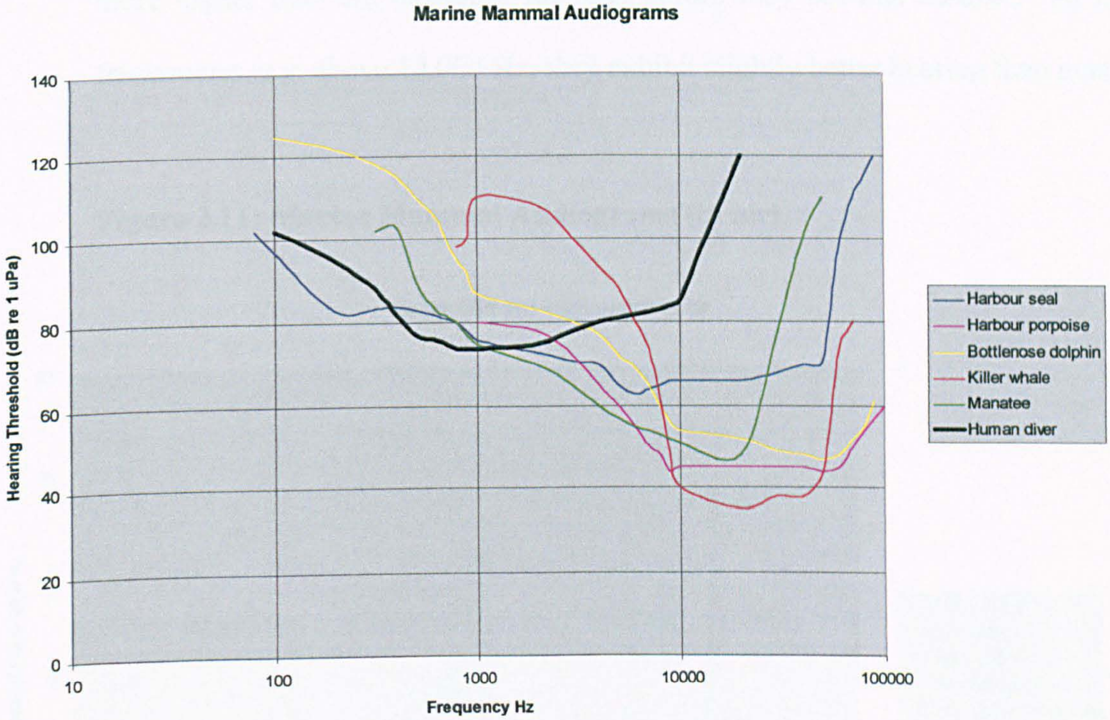
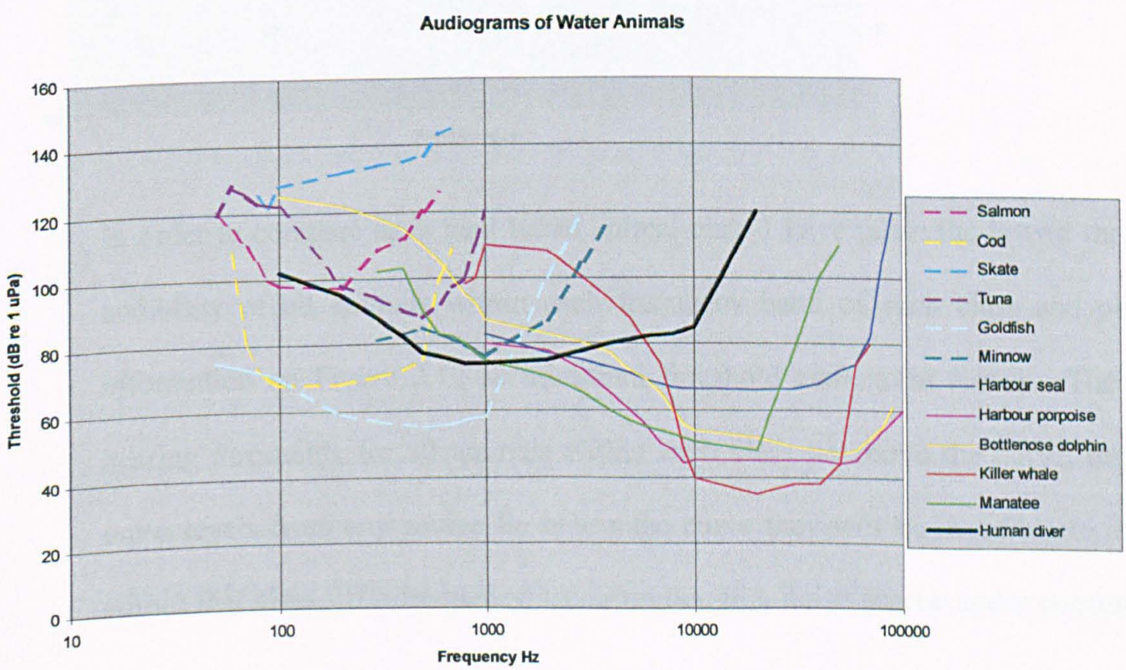
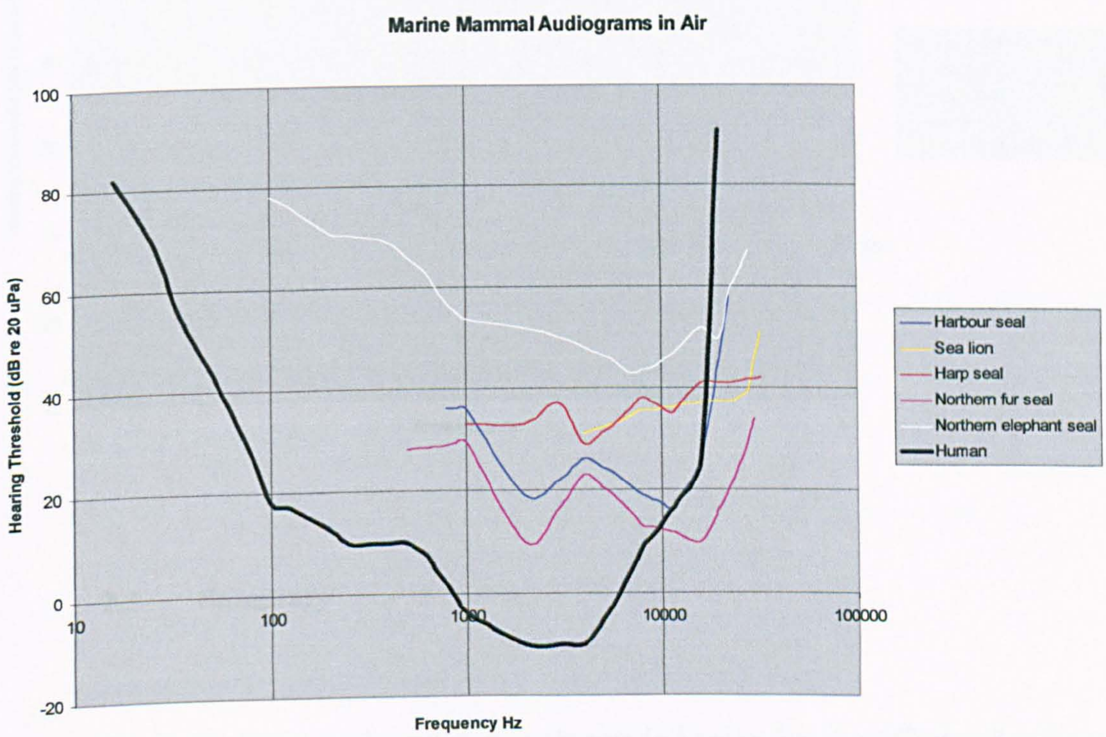


Figure 2.10: Comparison of Fish and Marine Mammal Audiograms



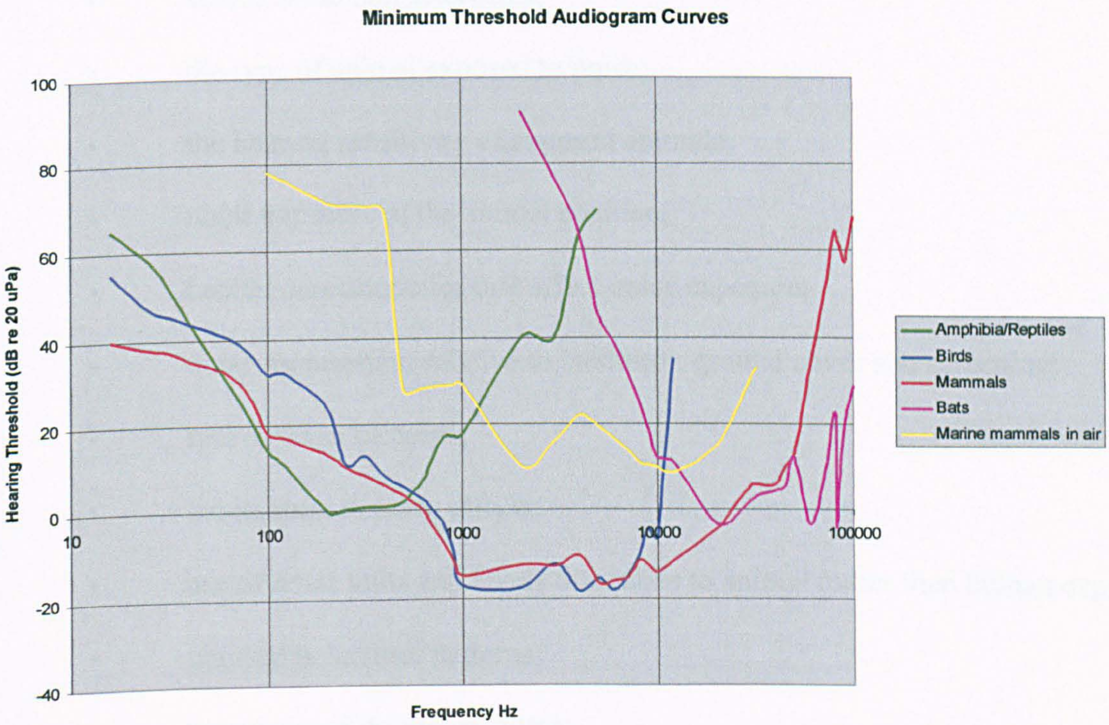
Hearing thresholds for some marine mammals when out of water are shown in Figure 2.11 (dB re 20 μPa). In this situation the animals typically show less sensitivity than man at frequencies below 10,000 to 16,000 Hz and require noise levels to be 20 dB or more higher than the threshold for man before they become audible. At the higher frequencies, e.g. above 10,000 Hz, they exhibit slightly better hearing than man.

Figure 2.11: Marine Mammal Audiograms (in air)



In order to compare each land based animal class I have taken the lowest threshold of audibility of all animals within each frequency band of each class and plotted the information on Figure 2.12 as minimum threshold audiogram curves. The range of hearing thresholds for all animals within each class lie above the curve, therefore, if noise levels from any source lie below the curve they will be inaudible to all species within that class. If a frequency spectrum due to a noise source under consideration is plotted on this base, it will provide a good indication of which animal groups are most likely to be affected and to what extent.

Figure 2.12: Minimum Threshold Audiogram Curves



2.3 Summary

The information reviewed in this chapter indicates that the effects of noise on sensitive animal communities are likely to be very variable, with effects often being different between species as well as between different groups or individuals within the same species. At first reading, no clear generalisation with respect to the effects of noise on different animal communities is evident, and the establishment of noise criteria by which the effects of noise from man's activities can be evaluated requires further work. A detailed analysis of the documented responses in order to develop an assessment procedure is undertaken in Chapter 5.

However, the review has enabled a number of important factors that may need to be considered by an assessment to be identified. Key factors will include the following:

- source noise characteristics;
- the type of animal exposed to noise;
- the hearing sensitivity of exposed animals;
- noise exposure at the animal position;
- habitat characteristics that affect noise exposure;
- noise propagation relative to landform, ground cover and screening;
- rate of onset of noise;
- habituation to noise effects;
- use of noise units and levels that relate to animal rather than human exposure;
- unusual behaviour patterns;
- seasonal and diurnal rhythms;
- what particular conditions must be fulfilled to produce a harmful chronic effect;
- short and long term effects;
- synergistic effects with other environmental factors;
- does the noise and the consequent response pose a threat to an individual's health, or a decrease to its well being, or an increased susceptibility to disease, or a shortened lifespan.

The above factors will introduce precautionary measures that will need consideration in any assessment process. These issues are discussed further in Chapter 4. Prior to that, the types of noise sources that have established documented responses are quantified in Chapter 3. The majority of the documented responses to noise relate to military sources, especially aircraft comprising both fixed wing and helicopters. Chapter 3 will quantify the typical noise levels and provide useful reference information for assessment purposes. It also compares military sources with their civilian equivalents to validate the use of the documented data for application to civilian as well as military assessments.

3. MILITARY AND CIVILIAN NOISE SOURCES

A number of existing literature reviews[281,295,296,297] are available and were mainly undertaken by military organisations, research bodies or national park authorities in support of Environmental Impact Statements for proposed changes to military training activities[298,299]. The main reviews and noisy activities under consideration tend to relate to projects in the US or Canada, and focus on the animal species to be found in those areas of proposed development, however, the various papers reviewed represent world-wide research into the topic and cover a broad spectrum of animal species.

Although a lot of the published work to date relates to the effects of military activities such as artillery and low-level flying on wildlife, these noise sources often have very close analogues within civilian life, which should enable the effects derived from the military studies to be applied with reasonable confidence to studies relating to civilian activities[297]. The various comparisons that can be drawn between military and civilian noise sources are presented in Table 3.1. Military activities also tend to cover all temporal and tonal situations likely to be encountered in practice, i.e. noise effects can be either intermittent (a low-level flyover) or continuous (ground based manoeuvres or depot activities); they can range from very high noise peaks (up to 150 dBLin or more close to heavy artillery) down to continuous background noise levels (the 'buzzing' of unmanned aerial reconnaissance vehicles such as Phoenix); they can encompass impulsive noises (shell fire and explosive detonations) or tonal events (turbines and rocket noise).

Table 3.1: Military noise sources and their possible civilian/natural equivalents

Military Noise Sources		Civilian/Natural Equivalents
Fixed –wing aircraft	Sonic boom	Civilian aircraft (Concord)
	Turbine noise	Civilian aircraft
	Propeller noise	Civilian aircraft
	Bombs/missiles	Construction, mining, thunder
Helicopters	Rotor blade	Civilian helicopters
	Turbine	Civilian helicopters
	Missiles	Construction, mining, thunder
Artillery (tanks/rocket launchers)	Engine/road noise	Roads, railways, off-road vehicles, construction plant
	Guns	Fireworks, blasting
	Muzzle blast	Fireworks, blasting
	Projectile shock wave	Fireworks, blasting
	Explosion (airborne)	Construction, mining, thunder
	Explosion (ground-borne)	Construction, mining, earthquake
	Rockets	Fireworks
Infantry	Small arms	Rifle clubs, clay pigeon shooting
Unmanned aerial vehicles	Engine noise	Radio controlled model aircraft

Not all of the review data relates to military sources since there is a lot of published information relating to the experimental effects of controlled noise exposures on laboratory animals. These studies have enabled the physiological effects of noise to be identified, i.e. the way the natural bodily functions such as the cardiovascular and endocrine systems respond to different levels of noise exposure, and in some instances have provided useful information relating to behavioural responses. The physiological and behavioural responses to noise have been described in greater detail in Section 2.1. However, many of the experimental exposures have involved exposing animals to much higher levels than they would normally encounter within their natural environment or from exposure to new development, therefore, care needs to be used when applying this information to real-life situations.

Other factors may also influence the experimental response compared to real-life since within a laboratory based exposure the surroundings are totally different to the normal habitat, which may alter not only the animal's responses but also the level and frequency of sounds that stimulate the animal's hearing mechanisms. The fact that laboratory animals are regularly handled and will also experience totally different regimes with respect to feeding, social interaction, and courting and mating is also likely to influence the response compared to a similar exposure in the wild.

For the above reasons, and also because it is important to know the effects of noise on communities as a whole and not just the individuals within a community, studies within the wild are most important. This brings us back to the majority of the work undertaken relative to the effects of military sources on National Park land and its wildlife, and a need to confirm that military sources are roughly equivalent to civilian analogues and vice versa.

An initial examination of the military sources in Table 3.1 suggests that there should be a good similarity between the noise characteristics associated with military sources and their civilian analogues. For example, in the case of fixed wing aircraft the aviation principles and types of motive power employed within military aircraft, i.e. those which cause sonic booms and turbine and propeller noise, are the same and, therefore, should result in similar noise characteristics in terms of their level and frequency content. However, there will be differences due largely to the different power requirements, speeds and operational characteristics used during military flying and training compared to civil aircraft operations. Rocket noise characteristics in particular do not have any directly comparable civilian equivalents although some fireworks may come close.

3.1 Fixed Wing Aircraft

Civil aircraft have to meet the standards set by the International Civil Aviation Organisation (ICAO), which are contained in Volume I of Annex 16 to the Convention on International Civil Aviation. For jet-powered aircraft, Chapter 2 of Annex 16, Volume I contains the noise standards that are applicable to aircraft designed before October 1977, and Chapter 3 contains the more stringent standards applicable to aircraft designed after that date[300]. Most modern airports have taken action to phase out the use of the noisier Chapter 2 aircraft thereby minimising the noise impacts associated with the arrival and departure of civil jet aircraft. Some thought has been given by the Committee on Aviation Environmental Protection (CAEP) as to whether new ICAO noise standards that would be more stringent than Chapter 3 are now desirable but at the present time no consensus has been reached.

With respect to aircraft noise data for noise assessment purposes it should be noted that ICAO noise standards are expressed as Effective Perceived Noise Levels (EPNL) measured in accordance with ICAO procedures, although some propeller-driven small airplanes and commuter category airplanes are certificated using A-weighted noise levels. The EPNL, expressed in units of EPNdB, is a measure that takes account of the tone corrected perceived noise level during the aircraft flyover and unfortunately does not allow direct conversion into other more common noise units such as A-weighted sound pressure levels used for environmental assessment studies. A crude conversion that allows derivation of an A-weighted peak value is EPNdB -13. However, like the

A-weighted scale, EPNdB noise levels have already been corrected to take account of the human perception of loudness, therefore, care has to be exercised when using such data against animals whose frequency response may be different.

If A-weighted noise data is sought for noise assessment purposes, then estimated airplane noise levels in dB(A) are available from a circular[301] prepared by the US Federal Aviation Authority. The circular provides data both for aircraft that have been certificated under 14 CFR Part 36[302] and those where no requirement currently exists. Noise levels are provided for take-off (6,500m from start of take-off roll) and approach (2,000m from the runway threshold). Therefore, their application may not always be appropriate to different circumstances without appropriate correction. For example, variations in aircraft weight and operating procedures may cause noise levels to differ.

In contrast to the design and operation of civil jet aircraft there are no noise standards that have to be met for military aircraft, consequently their noise levels are likely to be higher than for civil aircraft. This is hardly surprising considering the much higher speeds that military aircraft are required to operate at and the demands this places on greater power output from the jet engines. To apply the same noise suppression methods that are used for civil aircraft to military craft would result in an unacceptable loss of performance.

The modus operandi of military activities and hence their training is also very different to civilian flying and often involves high speed low-level flying. Most locations where animals might be exposed to civilian aircraft, i.e. nature reserves or National Parks, will tend to be remote from airports, by which time civilian jets will normally be flying at high altitude. The increased separation between the civilian aircraft and the ground will reduce the absolute noise level to which the animal is exposed but in turn will increase the time over which noise is likely to be detected by an animal. A characteristic noise trace for civilian jet aircraft is a gradual increase in noise above ambient for a period of several minutes followed by a gradual decrease in noise as the aircraft moves away. The review of animal responses undertaken in Chapter 2 indicates that many animals are able to use their sense of hearing and the rate of change of noise level to estimate the closeness of a source of noise. In this way, sources such as distant civilian aircraft will be identified by the animal as distant, which reduces the threat that they might otherwise pose and also reduces the physiological and behavioural responses generated by the noise. A reduction in responses will be beneficial because it minimises the energy expenditure.

If we look at the typical flight of military aircraft (in particular fixed wing but sometimes also helicopters), this is often close to the ground and at high speed in order to remain undetected by radar and to provide an element of surprise. As a consequence, noise levels do not show the same gradual change in level as for civilian operations because landform effects will provide much greater attenuation of noise. The result for animals at ground level is a much faster on-set time and a much higher noise level due to the proximity of the aircraft. The rapid rise in noise level is more likely to arouse the animal into an alert state, thereby initiating the physiological reactions described in Section 2.1, and is also more likely to produce a startle reaction compared to noise changes associated with civilian aircraft. Even military jet manoeuvres at higher altitudes produce noise levels significantly higher than civilian jets at equivalent altitudes.

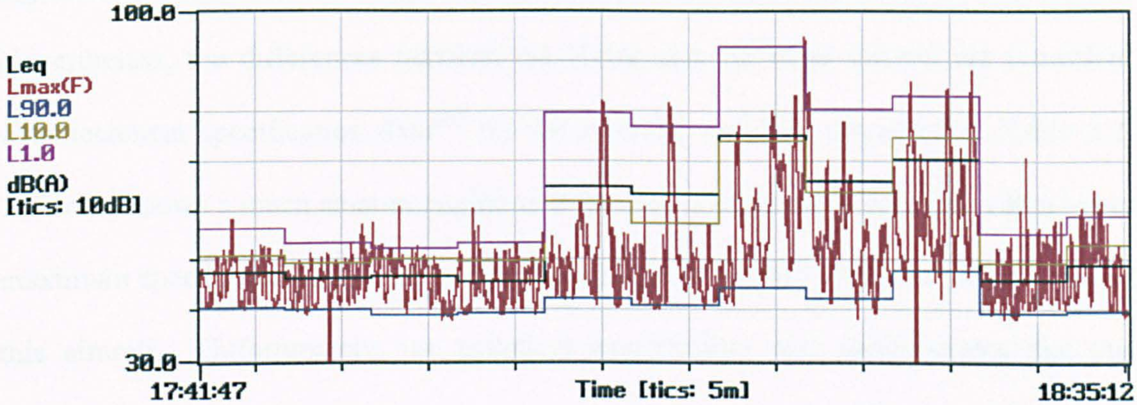
The minimum height normally permitted for military aircraft is 250 feet, although with appropriate authorisation low flying down to 100 ft is permitted in certain remote tactical training areas. Flying speeds are typically between 450 to 550 knots, which equate to 518-633 mph or 230-281 m/s. For an animal at ground level having, say, an angle of view of 90° upwards towards an aircraft flying at a height of 100 ft (30.5m) and an average speed of 255 m/s, the aircraft would be present within that arc of view and generating its peak noise level during a time period of only 240 milliseconds. For a larger angle of view such as 160° the exposure time would be 1.36 seconds. Such short exposure times reflect the source's ability to cause startle responses within unsuspecting animals.

In the UK, the MoD has applied a maximum permissible noise level of 125 dB L_{Amax} at ground level in order to limit annoyance to humans but no criteria have been developed specifically for animals. Some operational criteria have been developed for training areas in the USA and Canada, for example the U.S. Fish and Wildlife Service (USFWS) recommend that fixed-wing aircraft should avoid flying less than 150m above ground level (AGL) over eagle habitats during the breeding season[303]. Comparative noise surveys undertaken by the National Physical Laboratory for the MoD[304] have shown L_{Amax} noise levels for Harrier, Tornado and Jaguar aircraft, flying at a height of 100 ft at speeds of 480 knots, to be respectively 127, 124 and 122 dB. The initial rise of noise level, the on-set rate, is typically around 40 dB per second under the above flying conditions, however, at higher speeds the on-set rate will be much higher, e.g. at 526 knots a rate of 93 dB per second has been observed[305]. Data for the USAF Phantom F4 flying at an altitude of 100 ft has shown lower peak values and onset rates, being 114 dB and 26 dB/sec respectively.

Although low-flying jet aircraft are not normally permitted over population centres, some urban and suburban areas will be exposed to low-flying jet aircraft during aerial displays such as those presented by the RAF's Red Arrows team, which will have the potential to affect local wildlife species as well as domestic, zoological and farm animals present in the vicinity. In order to quantify the typical noise levels likely to be generated by this type of exposure I undertook noise measurements during a Red Arrows display that took place over Torbay on Wednesday 27 August 2003. Free-field noise levels were recorded using the equipment listed beneath Figure 3.1, which shows the noise trace during the event.

The equipment was calibrated against a reference signal of 94 dB at 1000 Hz before and after the recording, and the system exhibited zero drift. The equipment was set to monitor statistical noise parameters over 5-minute periods and to record L_{Amax} levels every second. The microphone was located at a height of 1.5m above ground level, although this position was also on the side of a valley facing towards the display, therefore, the height of the monitoring point above sea level was approximately 75m. The horizontal and vertical positions of the display team's Hawk aircraft relative to the monitoring position were, from the nature of their manoeuvres, extremely variable although the focal point of the display was approximately 2-3,000m from the monitoring point. The highest noise level was generated by a single jet that flew directly above the monitoring position at an estimated height of 100m (equivalent to 328ft) above local ground level. The weather conditions were hot, dry and calm with a heat haze.

Figure 3.1: Noise levels measured during Red Arrows display



	Noise Level, dB				
Time	L_{Aeq}	L_{Amax}	L_{A90}	L_{A10}	L_{A01}
1741-1835	66.9	94.6	40.3	60.8	79.4
Equipment:	CEL-90249 eNVi system hardware with NoiseMaster software; CRL MV 181A Pre-amplifier and cable; MK 224 Precision ½ inch electret condenser microphone + windshield; Psion Series 3c organiser to log and display data; and Larson Davies CA200 acoustic calibrator.				

The maximum noise level recorded as a Hawk jet passed directly above the monitoring position was 95 dB(A) (rounding to nearest whole number), which resulted in a maximum $L_{Aeq\,(5\text{-min})}$ of 75 dB. (Additional frequency analysis of the Hawk noise is considered in Chapter 5 in relation to the proposed assessment procedure.) From the aircraft's estimated flying height of around 300ft above local ground level, the equivalent noise level for a height of 100ft can be calculated as follows:

$$L_{Amax} \text{ at } 100 \text{ ft} = 95 - 20*\log_{10}(100/300)$$

$$= 104.5 \text{ dB}$$

The calculated L_{Amax} at 100ft of 105 dB is lower than values quoted above for low-flying Harrier, Tornado, Jaguar and Phantom (i.e. 127, 124, 122 and 114 dB respectively). However, variations between the actual and estimated aircraft heights will affect the calculated noise level, and different operating speeds will also be significant, therefore, the L_{Amax} for the Hawk at 100ft can only be indicative. Nevertheless, the differences between the Hawk and the other aircraft are consistent with technical specification data[306] for the aircraft, which is presented in Table 3.2. This data shows a much smaller engine size for the Hawk aircraft, coupled with a lower maximum speed capability, which in turn are likely to explain the lower noise level for this aircraft. Unfortunately, the technical specification data demonstrates that this information cannot always be used as a surrogate for noise data because although the aircraft in Table 3.2 are presented in descending order re: L_{Amax} noise levels at 100ft, one would expect the specification for the Phantom, i.e. higher engine thrust output and higher speeds, to generate a higher noise level than it does. Perhaps the lower noise level is due to better engine efficiency or better silencing of the exhaust/engine, or perhaps the referenced noise level is affected significantly by different operating characteristics.

Table 3.2: Technical specifications for some low-flying jet aircraft[306]

Aircraft	L_{Amax}	Engines	Thrust, kg	Maximum Speed, mph
Harrier	127	1 x Rolls Royce turbofan	9,752	737
Tornado	124	2 x MK101 turbofans	>7,257 each	691
Jaguar	122	1 x Westinghouse turbojet	4,944	710
Phantom	114	2 x General Electric turbojets	8,119 each	(1,485)[1]
Hawk	105	1 x Rolls Royce turbofan	2,359	645

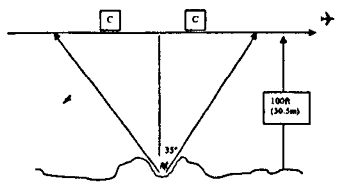
Note: 1 Speed for Phantom is equivalent to Mach 2.25 and reflects high-altitude rather than low-flying capability. The Tornado is similarly able to achieve Mach speeds of approximately 2.2 but this would not be applicable to low-flying operations.

Noise Onset Rate

An aircraft's performance, in terms of its height and speed, will produce large variations in the level, duration and rate of onset of noise at ground level. For example, at lower speeds the onset is gradual and noise levels fluctuate close to the maximum level for a relatively long period, however, at higher speeds the noise becomes near-impulsive with a much faster rates of onset and decay. During controlled trials relating to Tornado GR1 aircraft flying at speeds up to and beyond the normal UK flying limits, average maximum noise levels did not exceed 125 dB(A) or 140 dB wideband peak[307]. The onset rate was reported as always <100 dB/sec for flights within current UK low flying limits, which indicates that the rate was regularly higher than the levels referenced in the preceding paragraphs and shows the importance of knowing the actual flight parameters before attempting to determine noise levels at the animal position.

However, the above on-set rates will be most applicable to individuals in the open having a large angle of view to the aircraft approaching and flying away from the point of maximum exposure. For smaller animals close to ground, their angle of exposure will be less due to screening provided by landform and other habitat characteristics such as rocks, burrows and vegetation. In the case of a 90° angle of exposure mentioned above in relation to aircraft flyovers, the noise changes over this segment (time 240ms) would amount to a rise from ambient, firstly to 116 dB(A), then to 127 dB(A), and finally back down to 116 dB(A) and then to ambient conditions, assuming a flyover of a Harrier jet at 100 ft and 526 knots. The situation for an animal within a rock gully or crevice, or inside a burrow, would be different, with the exposure time being much less. For example, for an angle of exposure of 70° the pass-by time of the aircraft at maximum speed whilst it is unscreened would be about 167 ms; I have shown this situation schematically in Figure 3.2.

Figure 3.2: Example of calculated exposure time for animals at ground level exposed to low flying aircraft



Exposed flyover, 2C = 2 x (30.5 x Tan 35)
= 42.7 m

An average speed of 255 m/s (500 knots)
= 0.255 m/ms

Exposure time = 42.7/0.255
= 167 ms

In reality, therefore, the on-set rate for animals may be much higher than that indicated by reference data that has been collected relative to human exposure levels. For animals that are well screened from the approaching aircraft there may not be the progressive increase in noise levels over time as the aircraft gets closer - for which the onset-rate can be as high as 90 dB per second or more. Instead, the animal will be exposed to the typical ambient noise level within its habitat (together with an increasing proportion of noise reflected into the screened zone as the aircraft gets closer) followed by an almost instantaneous rise in noise level as the aircraft suddenly breaks into the unscreened angle of view. Such effects will alter the on-set rate and, subject to the sensitivity of the animal and other local factors, may affect the response of the animal.

Different onset rates are, therefore, likely to arise for different animals and for different habitats, especially when the landform or other structures provides a substantial degree of screening to the approaching aircraft. Landform structures such as cliffs, steep rocky mountain sides and canyons are likely to provide a high degree of screening to aircraft approaching from behind and eventually over the landform. Birds, sheep and other animals on the protected side would then experience a rapid change in noise levels. In such cases, having aircraft approach from the open face would minimise startle effects. Screening forms one of the precautionary factors discussed later in Chapter 4.

Mention has been made of the possible noise effects associated with animals in burrows, for example will the dimensions of the burrow (diameter and depth) influence the noise levels and frequencies transmitted to animals within the burrow. Also, to what extent does the burrow act as a Helmholtz resonator to sounds travelling across the mouth of the burrow? There is little published data to establish what noise levels will be perceived within burrows, however, it seems likely that the immediate landform, landscape and habitat features such as burrows or rocks will play an important part in the actual exposure of animals to jet noise and other military or civilian sources. Noise levels referenced so far have been based on ground level receivers but for animals that live in trees or are themselves flying during the aircraft flyover, the source to receiver distances will be less and the angle of exposure will be greater, which will increase the noise exposure in terms of both level and duration. The need to consider habitat characteristics during an impact assessment is discussed further in Chapter 4.

For aircraft or other projectiles that travel in excess of the speed of sound a sonic boom will be generated, however, for a boom to reach the ground the aircraft speed relative to the ground must be greater than the speed of sound at the ground otherwise the boom will be refracted upwards and not reach the ground. The speed of sound in air at 20°C is 340 m/s, which is roughly equivalent to a speed of 750 mph, however, a decrease or increase in temperature results in a corresponding decrease or increase in sound speed. For example the air temperature at 30,000 ft drops to -45°C, which reduces the speed of sound to about 670 mph, which in turn is less than the speed of sound at ground level causing sound rays to be refracted upwards. In order for an aircraft at 30,000 ft to produce a sonic boom audible at ground level it must travel at a speed of at least 750 mph or Mach 1.12. (The Mach number is the ratio of an aircraft's speed to the speed of sound and Mach 1.0 equals the speed of sound. The Mach speed for the example given at 30,000 ft is 750/670 which equals1.12)

The energy range of a sonic boom is focused within the 0.1 to 100 Hz frequency range and, for most fighter aircraft, lasts for about 100 milliseconds. The boom will be greatest under the flightpath and in general the greater the aircraft's altitude the lower the overpressure on the ground but the greater is the boom's lateral spread, which exposes a wider area to a boom of lower intensity. The ground width of the boom is typically one mile for each thousand feet of altitude and, depending on the aircraft's altitude, the boom reaches the ground 2 to 60 seconds after flyover. The speed restrictions on low flying aircraft do not allow sonic booms to be produced close to the ground, although it will be seen in the section dealing with artillery and rocket noise that rocket missiles are propelled at supersonic speeds at heights as low as 250m (820 ft), which will increase the overpressure at ground level but reduce the area affected.

Sonic booms from military aircraft have produced forces of between 500-1500 Newtons/m^2 measured in building elements at ground level compared to 100-250 N/m^2 from civilian aircraft.

3.2 Helicopters

Some of the differences/similarities between military and civilian jets are common to military and civilian helicopters, although any variations are unlikely to be as great since civilian helicopters do not fly as high as civilian jets. Nevertheless, so far as military training is concerned, flights at very low levels above ground are common place, more so than for civilian flying, and will tend to produce faster rise times and higher noise levels than for civilian flying. For example, modern warfare uses the Apache helicopter (see Figure 3.3) or similar aircraft to mount surprise attacks by again flying low and fast to use the landform to screen the approach of the aircraft. Due to the high payload required for carrying heavy armament etc. the power needed to be provided by the engine is likely to be higher than for civilian helicopters, which again will raise the overall noise output. A comparison of noise levels produced by some military and civilian helicopters is provided in Table 3.3 under equivalent operating conditions, i.e. akin to normal take-off, landing and flyover conditions.

Figure 3.3: The AH-64 Apache Attack Helicopter

Increased payloads for armaments and new technology, coupled with faster speeds and rapid low-flying capability, require more powerful engines that result in higher noise levels at ground level

Unfortunately there is very little published data relating to military aircraft and helicopters that enables direct comparison with civilian aircraft. This is mainly because military aircraft do not have to demonstrate compliance with noise standards applicable to the movement of aircraft to and from civilian airports. However, the two military helicopters shown in Table 3.3, the Apache and the Lynx, do have noise data collected under civil aviation certification conditions, which enables direct comparison with civil helicopters.

Table 3.3: Comparison of EPNdB noise levels and other vehicle specifications from military and civilian helicopters[302,306,308,310]

Helicopter	Power (No. engines x kW)	Maximum Gross Weight kg	Noise Level EPNdB		
			Take-off	Landing	Flyover
Military					
AH-64D	2 x 1671	7,746	95.8	98.4	96.2
Lynx MK7	2 x 746	4,763	92.0	97.7	91.7
Gazelle	1 x 440	1,800	-	-	-
Civilian					
Bell 212	2 x 1345	5,080	91.8	95.8	94.7
BK 117	-	-	88.8	90.4	92.6 (89.7)
S61	-	-	95.9	94.0	92.6
AS332	2 x 1570	9,150	92.5	95.1	91.5
SA 365N	2 x 550	4,250	91.3	92.6	90.9
A109	2 x 300-540	2,600-2,850	90.9	93.0	90.4 (89.1)
Bell 47G	1 x 155	1,450	<85	89.6	90.3
S76	2 x 730/540	5,300	90.0	92.3	89.0
BO 105	2 x 315-375	2,600	89.1	91.7	88.4 (90.9)
Hughes 500D	-	-	88.7	88.7	87.4
AS350	1 x 460-555	2,250	89.3	91.3	87.3 (84.2)
AS355	2 x 340	2,540	88.5	91.9	87.2 (86.2)
SA 341G	-	-	92.6	89.6	86.1
Hughes 500C	-	-	85.1	87.7	85.8
Bell 206L	1 x 485	1,880	85.9	90.3	85.8
Hughes 300	-	-	<85	<89	80.6
MD Explorer(1)	1 x NA	2,835	-	-	83.1 (81.2)
MD 520N(1)	2 x NA	-	-	-	80.2
MD 600N	1 x NA	<2,835	-	-	79.0

Notes: (1) Comply with FAA's newly defined quiet technology category for use in environmentally sensitive areas such as the Grand Canyon National Park, and employ NOTAR (No Tail rotor) anti-torque system.

Noise levels in ( ) represent recent FAA noise data.

The noise data has been presented for the two groups in descending order relative to flyover noise levels since this condition is likely to have the greatest widespread effect on any animal communities at ground level. The Apache noise levels tend to be the highest of all the tabled aircraft under all conditions, whereas the Lynx tends to be similar to the noisier civil helicopters. Using the power and weight specifications of the Gazelle (primarily an observation and reconnaissance helicopter), these indicate that this machine's noise level is likely to be similar to the single turbine Bell 206L, i.e. very much less than the latest Apache attack helicopter. Therefore, there are similarities between the noise levels generated by military and civilian helicopters, with a potential for the greater power demands of military helicopters for payloads such as armaments etc. to produce higher noise levels. The mode of operation will also produce noise differences.

All the above noise levels are, as for the fixed wing aircraft, in units of EPNdB measured in accordance with ICAO procedures. Therefore, for noise assessment purposes, some conversion will be required such as the derivation of an A-weighted peak value by subtracting 13 from the EPNdB. However, since EPNdB noise levels, like the A-weighted scale, have already been corrected to take account of the human perception of loudness, care must once again be exercised when using such data against animals whose frequency response may be different.

As a consequence of the proposed use of the Apache helicopter for training purposes at the Otterburn Training Area in the Northumberland National Park, I monitored A-weighted noise levels whilst Westland GKN's first production model, the WAH-64, was undergoing rotor track balancing work at the factory in Yeovil. The WAH-64 Apache helicopter is based on the US Army's AH-64D but with UK specific mission equipment and Rolls Royce Turbomeca RTM322 engines. The test flights involved balance weights added to the rotor blades, and the aircraft flying under a medium load fitted with dummy missiles.

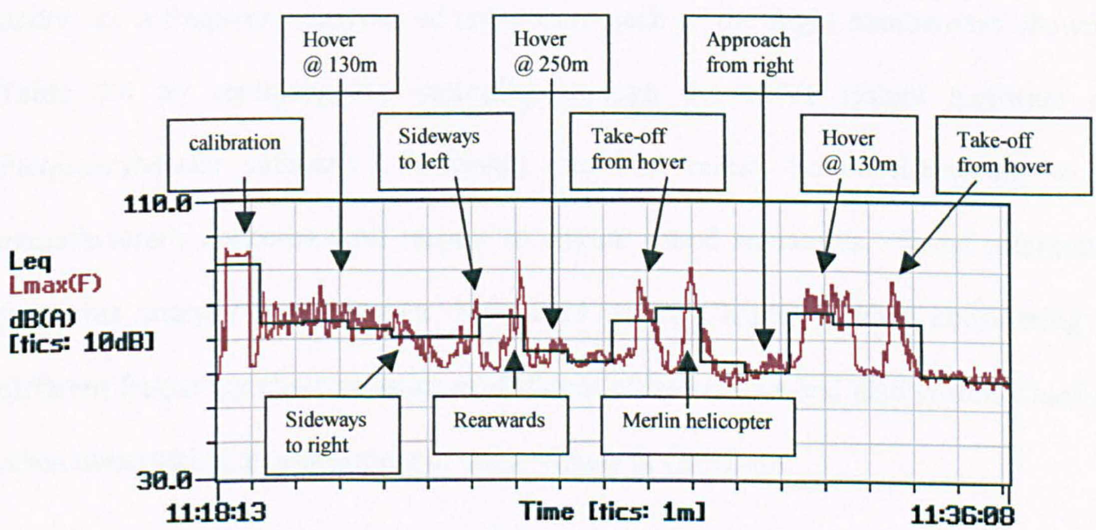
Equipment used to undertake the measurements comprised the following, which was calibrated before and after measurements and exhibited zero drift:

CEL-90249	eNVi system hardware and NoiseMaster software;
CRL MV 181A	Pre-amplifier and cable;
MK 224	Precision ½ inch electret condenser microphone + windshield;
Psion Series 3c organiser to log and display data;	
Sony TCD-D8	Digital Audio Tape Recorder; and
Larson Davies CA200 acoustic calibrator.	

The microphone was located in a free-field position at a height of 1.2m and at a distance of approximately 130m from the centre of the test runway and main hover point. The test runway was grass and the ground in between the runway and the monitoring point was also grass. Meteorological conditions supplied by Westland GKN for the test flight were a wind direction of 230°; a wind speed of 10 knots gusting to 20 knots (equivalent to 5 to 10m/s); humidity 71%; temperature +15 °C; and barometric pressure 997 mbars. The wind direction was blowing approximately from the monitoring location towards the runway and, coupled with the strength of the wind, resulted in a wind gradient that caused a strong upward refraction of sound from the helicopter. This would significantly have reduced noise levels compared to neutral conditions or a downwind monitoring location.

The aircraft performed a number of movements which included hovering just above ground (this would be similar to the in-ground effect (IGE) hover), turning whilst hovering, flying sideways to the right and left, flying backwards, and flying forward and rising from hover to enter a circuit loop. The latter manoeuvre can, for noise assessment purposes, been taken to be similar to a take-off operation, although it was not from a stationary position and, therefore, is likely to underestimate the noise levels. Maximum A-weighted noise levels were recorded every second together with the L_{Aeq} noise levels recorded every minute. The various flight manoeuvres are identified on Figure 3.4, which shows the noise trace that was recorded throughout the test flight.

Figure 3.4: Noise measurements during an Apache WAH-64 test flight at Yeovil showing different flight manoeuvres



The data was analysed to provide a measure of the noise levels for each individual manoeuvre and the results are presented in Table 3.4. The highest L_{Amax} noise level of 92.3 occurred during the rearward flight when the engine exhausts were facing towards the microphone. In terms of highest sound energy during a flight event, the noisiest L_{Aeq} was 78 dB, which occurred for both the rearward flight and the second hover, both at distances of approximately 130m. For comparison, the Merlin EH101 that flew past during the test, produced a L_{Amax} noise level of 90.7 dB and an L_{Aeq} of 79.7 dB, the latter being higher than the Apache.

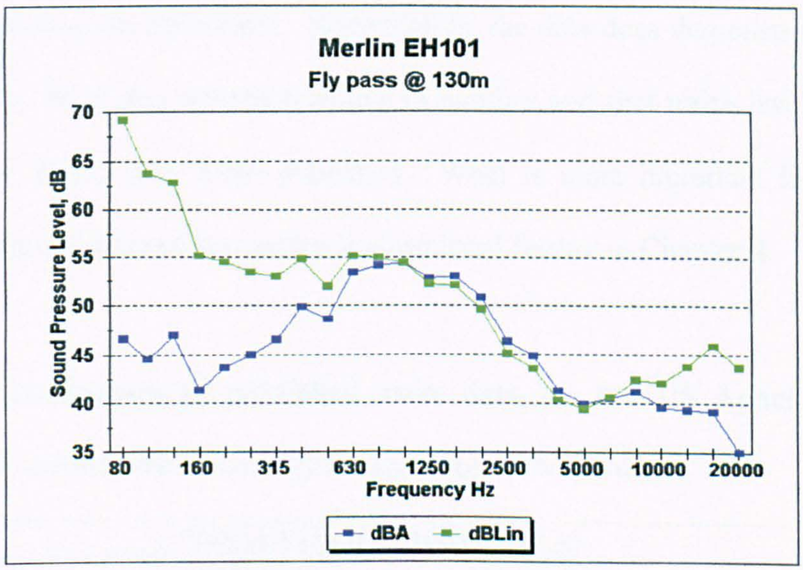
Table 3.4: Noise levels for different flight manoeuvres measured during an Apache WAH-64 test flight at Yeovil

Event	Event time, s	L_{Aeq} dB	SEL dB	L_{Amax} dB
Hover @ 130m	120	74.8	95.6	85.1
Sideways to right	60	70.0	87.8	78.0
Sideways to left	48	71.3	81.1	81.3
Rearwards	45	78.0	94.5	92.3
Hover @ 250m	32	66.4	81.5	70.0
Take-off from hover	41	77.0	93.1	86.8
(Merlin EH101)	(47)	(79.6)	(96.3)	(90.7)
Hover @ 130m	79	78.0	97.0	85.9
Take-off from hover	41	76.0	92.1	86.9

The unweighted data and calibration signal recorded on the DAT recorder were used to undertake a frequency analysis of noise from each of the flight manoeuvres shown in Table 3.4 by replaying the recording through the eNVi system hardware and FrequencyMaster software. However, this data cannot be published due to the manufacturer's concerns with respect to engine sound signatures. Some information from this analysis has, however, been used within Chapter 5 when considering the different frequency characteristics of different noise sources and also within Chapter 6 when undertaking an assessment of noise effects at Otterburn.

The frequency analysis for the fly pass of the Merlin EH101 is shown in Figure 3.5. The noise levels do not reflect the maximum sound pressure levels during each event but an average of the fluctuating noise levels throughout the flight event. As with many military noise sources, there is a significant amount of sound energy within the lower frequencies, i.e. below 500 Hz, and the same situation was present for the data for the Apache. When using the A-weighting to reflect the frequency response of the human ear, this sound energy is discounted from the noise measurements. Therefore, when considering the noise impacts on wildlife, it may, subject to the hearing frequency range of the species being affected, be more appropriate to include more of the low frequency sound energy within the noise level for assessment purposes

Figure 3.5: Third octave band frequency analysis of noise level recorded during flypass of Merlin EH101 helicopter at a distance of 130m



Some operational noise levels for the US Army AH64 at 100m in terms of an L_{Aeq} for IGE hover and SEL values for take-off and landing have been published[308] and enable some comparison with the above data for WAH-64. Data measured for the WAH-64 was slightly further from the source (130m) and has been corrected to a distance of 100m assuming sound propagation under hemispherical conditions. The respective sets of noise measurements are shown in Table 3.5. None of the Apache's test manoeuvres corresponded to a 'landing', therefore, no comparative data is available.

The data in Table 3.5 suggests that the noise levels from the WAH-64 are approximately 3 dB(A) higher than those published for the AH-64. However, the noise data for the AH-64 was gathered using an array of 6 microphones, which enabled any flight alignment over two microphones subject to wind conditions, with the remaining four microphones recording sideline noise levels. In contrast, the noise data measured for the WAH-64 used a single sideline microphone location and strong wind speeds were blowing from the microphone to the source. Bearing in mind the differences in measurement techniques and ambient wind conditions, and the typical variations often encountered in environmental noise measurements from one day to another, the noise data shows fairly good agreement. Nevertheless, the data does demonstrate how noise levels can vary from one reference source to another and that noise levels in practice may often be higher than those published. What is more important is whether the variation is significant, and this matter is considered further in Chapter 4.

Table 3.5: Comparison of published noise data for the US Apache helicopter AH64[308] with noise levels measured for the MoD's WAH-64

Noise Levels at 100m, dB(A)					
Manoeuvre	**AH64**		**WAH-64**		**Difference**
	L_{Aeq}	**SEL**	L_{Aeq}	**SEL**	
IGE Hover	77.7	-	80.3	-	+3.3
Take-off	-	92.1	-	95.4	+2.6
Landing	-	95.0	-	-	-

Helicopter noise is probably the most complex of the military and civilian noise sources likely to be encountered by wildlife due to the mix of noises emanating from the engine, the gearbox, the rotor blades and the numerous interactions that occur between the rotors, rotor vortices and turbulent airflows. In addition, the actual noise level and frequency content at any given receiver can vary considerably according to the spatial relationship between the receiver and the helicopter as well as its direction of movement in relation to the listener. It is possible that the more extreme and varied responses of animals to helicopter noise may be due to the confusion generated by the complexity and interaction of the various sources of noise on a moving helicopter.

The rotary movement of the helicopter's blades produces regular pulsatile noises, which occur at characteristic blade passing frequencies (BPF) dependent on the number of blades and their rotation speed. Whereas the engine and gearbox noise tends to be broadband, the blade loading noise associated with the rotation of the blades is impulsive, occurring at the fundamental and at harmonics of the BPF[309]. Unfortunately for noise assessment purposes, each helicopter model tends to have a different noise signature according to the number, type and design of rotors, the number of blades per rotor, and the number and type of engines. Within models, further operational characteristics such as blade load, blade speed, weather conditions, angle of tilt, aircraft speed and aircraft activity will also influence the spectral content of noise heard by an animal.

Factors such as the number of blades, blade tip speed and blade loading will determine the complexity of harmonics or multiple-frequencies associated with 'blade-slap' noise[310], and the greater the complexity the more likelihood there is that the frequencies may extend into the frequency ranges more audible or more annoying to a particular species of animal. Rotor-vortex interactions also have the ability to increase the impulsive BPF harmonics in the higher frequency bands[311], which adds further features to the perceived noise levels that might trigger reactions within animals. However, few studies on wildlife have attempted to relate the frequency content of helicopter noise to the biological characteristics of the animal and its response. From the general information available, it would appear that the reaction of an animal is likely to vary according to the specific type and model of helicopter intruding into its habitat. Of the studies reviewed by the US Army Corps of Engineers Construction Engineering Research Laboratories (USACERL) most related to animal exposure to the Hughes 500 and Bell 206 helicopters. From the information in Table 3.3 it can be seen that these craft have very similar noise levels and, being powered by a single engine, have noise levels towards the lower end of the range. Larger aircraft with more engines, more blades, more loading and faster speeds are likely to generate much different noise signatures and consequently could cause different effects.

Helicopters produce very low frequencies, typically 20-30 Hz, as a consequence of the blade slap determined by the number of rotor blades and their rotating frequency. Since the wavelength of low frequency sounds is often greater than the dimensions of noise screens, low frequency sounds will be directed around barriers (see Chapter 4 for further consideration of this subject). For example, a frequency of 20 Hz has a wavelength of 17.2m (wavelength = speed of sound in air/frequency), which is much greater than man-made noise barriers, small buildings and localised landform changes. As a consequence, low frequency sound energy will be deflected much further than high frequency sounds into the acoustic shadow provided by a noise screen.

The fact that low frequency sounds will penetrate further into screened areas adds to the difficulty that animals have in defining the source direction of low frequency sounds. Helicopters clearly generate stronger responses in animals than other noise sources but it is not clear from the available evidence whether this is due to the low frequency noise or the confusion generated by the complexity of noise components that combine to form helicopter noise signatures, or a combination of both (see earlier review of responses to helicopter noise in 2.1.6). Low frequency resonance of body cavities may also be a trigger for animal responses, in which case the threshold is likely to be different for different sized animals, and seismic contributions or other such vibrations/movements within the habitat, ground or vegetation might also play a part. Anecdotal evidence from Belgrade zoo during the recent Kosovo fighting reported that zoo animals started calling sometime before bombs started to fall on the city, presumably having picked up advance warning through low frequency sounds generated by aircraft or missiles flying towards the city.

Comparative technical data for helicopter operating characteristics, number of engines, size, aircraft loading, and rotor blade numbers and diameters is available for different makes and models of helicopter[306]. The information covers all modern helicopters as well as more obscure makes/models that may have been in use during earlier studies of animal responses to helicopters. Using this data, it may be possible to equate documented responses to known helicopters, to other aircraft of similar size and operating characteristics.

A limited database of helicopter noise levels can be found in the U.S. Department of Transportation's Helicopter Noise Model (HNM)[312]. The model provides noise levels for 16 helicopters and their various equivalencies under recognised flight procedures at distances ranging from 200 to 10,000 ft. The noise data is presented as A-weighted SELs for stationary operations, which include ground idle (GIDLE), flight idle (FIDLE), hover in ground effect (HIGE) and hover out of ground effect (HOGE), and moving operations, namely take-off (TO), approach for landing (APPR) and level flyover (LFLO). To account for in-flight directionality, data is given for right and left hand sides (at 45° elevation) and centre (90° elevation). For the level flyover, the data represents a single typical speed. The highest noise levels, i.e. at 200 ft or 61m, are presented in Table 3.6 and enable further comparisons to be made for assessment purposes. Subject to the type of flight operation, differences of between 8-18 dB(A) are seen between different makes and models of helicopters.

Table 3.6: Operational noise levels from Helicopter Noise Model[312]

SEL A-weighted at 200 ft (61m)									
Make	**Model**	**Equivalents**	**Stationary**				**Moving (90° elevation)**		
			GIDLE	**FIDLE**	**HIGE**	**HOGE**	**TO**	**APPR**	**LFLO**
Bell	B212	B204/205	-	-	87.7	-	95.5	97.8	97.3
Sikorsky	S61		-	-	85.9	-	96.3	94.8	95.0
Boeing Vertol	CH47D		71.6	-	86.3	92.3	92.8	97.7	92.3
Hughes	H500D	S330/OH6A R44/MD500 R22HP	64.9	-	79.8	-	88.5	90.9	86.9
Boelkow	BO105	B412	-	-	82.9	-	89.9	93.1	91.8
Aerospatiale	SA3305	SA332	-	-	86.6	-	97.1	96.1	95.4
Bell	B206L	B206B	64.3	-	76.1	-	84.8	89.5	85.1
Agusta	A109		-	-	83.3	-	95.1	98.5	92.3
Aerospatiale	SA341G	BOH58	-	-	80.1	-	93.5	90.3	89.8
Sikorsky	S65		-	-	88.7	-	97.3	99.8	99.5
Sikorsky	S70		-	-	90.8	-	92.1	100.0	101.0
Sikorsky	S76	S58/B430	57.7	-	82.3	-	92.6	96.3	92.9
Aerospatiale	SA365N		72.1	-	87.3	89.0	91.8	97.2[1]	90.8
Aerospatiale	SA355F		62.8	-	80.9	86.5	93.8	92.0	89.5
Aerospatiale	SA350D	SA316 B407	54.2	-	77.5	-	92.5	90.9	89.7
Bell	B222	B230	58.8	-	74.2	84.3	90.6	94.3	92.7
Range			54-72	-	74-91	84-92	85-97	90-100	85-101
Difference			18	-	17	8	12	10	16

Notes: 1. Data is average for right and left sides rather than for centre.

GIDLE = ground idle
FIDLE = flight idle
HIGE = hover in ground effect
HOGE = hover out of ground effect
TO = take-off
APPR = approach for landing
LFLO = level flyover

3.3 Land Vehicles

With regard to land-based activities such as the movement of wheeled or tracked vehicles such as trucks, transporters and tanks etc., the engine designs and performance characteristics are either similar to ordinary road-going vehicles, or, in the case of the very large military vehicles, similar to construction plant used on heavy engineering contracts. Some examples of maximum drive-by noise levels produced by military vehicles[313] are given in Table 3.7 together with equivalent levels for construction plant derived from BS 5228:Part 1:1997 'Noise and vibration control on construction and open sites'. The construction plant noise levels relate to the larger machinery more commonly associated with motorway construction or opencast workings, and which in some instances are tracked like the military vehicles.

Table 3.7: Maximum drive-by noise levels at 10m from military equipment[313] and equivalent sized construction plant, dB(A)

Military					Construction	
Machine	Engine	Weight	Noise level		Machine/weight	Average noise level
			Concrete	Soft ground		
AS90 (tracked)	600 hp	-	102 at 52 kph	-		
MLRS (tracked)	8 cylinder diesel	24,756 kg	108 at 64 kph	85	Grader/24,520 kg	86
MLRS (tracked)			106 at 40 kph	-		
FV432 tracked troop carrier	RR K60	15.3 tonnes	94 at 35 kph	93	Scraper/20t Crawler/14.2t Tractor/14,270kg	77 79 89
Warrior OPV (tracked)	RR CV8	24,500 kg	101 at 52 kph	90	Grader/24,520 kg	86
Challenger tank (tracked)	RR CV12	62,000 kg	108 at 52 kph	92	Tractor/77,870kg	87
Chieftain tank (tracked)			108			
Crusader				85		
Commander				81		
Spartan CVR (tracked)	4.2 litre	8.17 tonnes	98	-	Tractor/8,820 kg	89
Stormer			97	80		
DROPS (wheeled)			84 at 52 kph	-		

Generally, for an equivalent size or weight of construction plant the noise levels tend to be lower than for the military vehicles. This is consistent with the findings for the aerial sources and again is due to the power and speed requirements of the military vehicles.

Noise levels for the military vehicles travelling on a hard concrete surface are often 10 to 20 dB higher than for soft ground, which is a function of the large surface area provided by the tracks on the reflective road surface. Noise levels over soft ground are more in keeping with construction plant and in the majority of instances both military and construction sources are more likely to be operating over unmade ground. In cases where sources are operated on hard reflective sources then appropriate amplification of noise levels would need to be taken account of in an assessment.

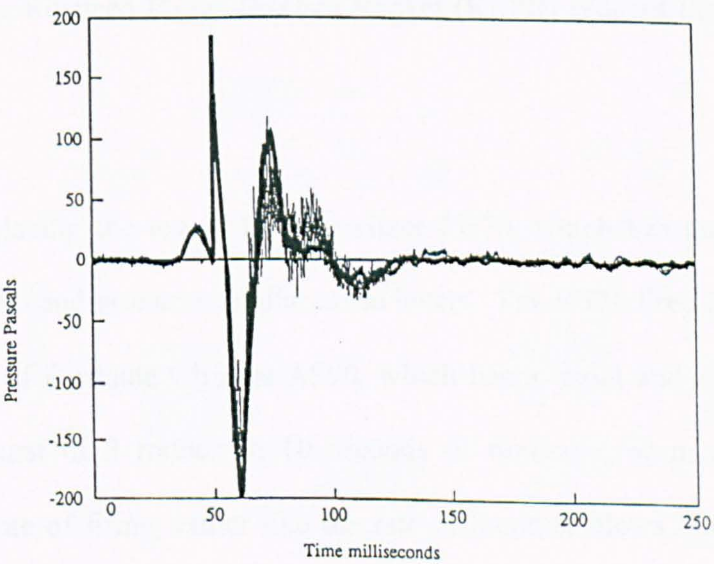
3.4 Artillery and Rockets

Weapon systems, which include features such as shell fire, rocket launches and explosions do not reflect typical everyday occurrences nevertheless some analogues do exist. For example, the construction and mining industries can often involve noisy events having a fast rise-time and shock-wave effects, especially during blasting. Fireworks can also present similar noise characteristics to some explosions and rocket events though of course the intensity of either would depend upon the proximity of animals to the noise source.

A typical time history associated with the firing of heavy artillery[314] is shown in Figure 3.6, which shows the firing of 155mm shells from the MoD's latest Artillery System AS90 using the highest charge, 7 White (7W), together with the time history of an equivalent charge of plastic explosive PE4. The time histories of the two sources are virtually identical and indicate that the explosive detonations associated with construction and mining operations are likely to produce similar noise events to artillery noise. There may, however, be differences with respect to their tonal content, especially over different charge quantities. The noise measurements were undertaken at distances of 200 and 400m from the AS90, which resulted in maximum peak noise levels of 143 dBLin at 200m and 136 dBLin at 400m.

The peak pressure of approximately 180 Pascals (or 180 N/m^2) in Figure 3.6 is equivalent to a peak sound pressure level of about 139 dBLin, which is roughly equivalent to the pressure changes generated at ground level from sonic booms generated by civilian aircraft (100-250 N/m^2).

Figure 3.6: Comparative noise level time histories during firing of 155mm shells by AS90 artillery and an equivalent plastic explosive PE4[314]



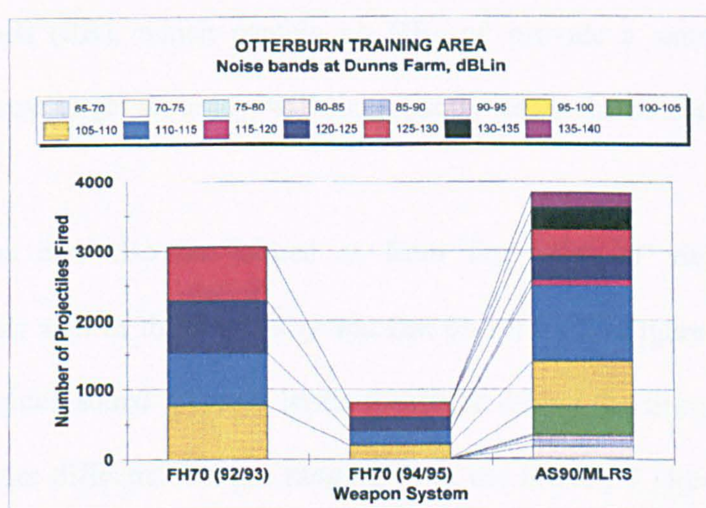
The rise-time associated with the production of the peak noise level of 139 dB is only about 20 milliseconds, which reflects the potential for this type of noise to cause a startle response within animals. It can be appreciated that for such a sudden onset of noise the physiological and behavioural responses induced within an animal are likely in many instances to be instantaneous. Instead of the body initially making reflex adjustments to cope with any threat, the body may make the adjustments and initiate the actions at the same time, in which case the animal may not be fully prepared for the consequences of its actions, i.e. it may not be fully aware of its immediate surroundings, which might represent more of a danger than the source of the noise.

From measurements undertaken at the training areas at Larkhill Range on Salisbury Plain and at Otterburn Training Area (OTA) in the Northumberland National Park, the maximum source sound power level for the firing of either the latest AS90 or MLRS weapon systems is similar at 196 dB L_{WA}. In the case of AS90, progressively reducing the charge weight reduces the sound power level and the lowest charges produce a level of about 167 dB L_{WA}. Likewise for the MLRS, changing from the full bore practice M28 rocket to the Reduced Range Practice Rocket (RRPR) reduces the noise level by about 23 dB.

The AS90 is replacing the towed field howitzer FH70, which has the same 155mm calibre as the AS90 and produces similar noise levels. The FH70 fires 155mm shells at a maximum rate of 6/minute whereas AS90, which has a 'scoot and shoot' capability, can provide a burst of 3 rounds in 10 seconds or 6/minute, or in sustained mode 2/minute. The rate of firing, rather like the rate of hammer blows during piling, will also have some bearing on the noise exposure of animals in the vicinity. The airportable 105mm light gun likewise fires at a maximum rate of 6/minute but generates noise levels between 2 to 6 dB lower than AS90, MLRS and FH70, subject to the charge weight.

At most training areas, shells will not be fired from just one gunspur but there will be a number of guns firing from a number of different gunspurs towards a common impact area. For animal communities close to the gunspurs the noise exposure will be a combination of different peak noise levels due to the different distance and screening effects from each gunspur together with the number of rounds fired from each spur. For a given receiver, one possible way of reviewing a noise effect is to consider the totals of the number of noise events from each gunspur by placing these into different noise bands. This approach can be useful where there is a 'change' to a baseline condition, such as a change in equipment, layout or operational practice.

Figure 3.7: Analysis of annual heavy artillery noise events experienced by a receiver on the OTA range for different years and different weapons systems



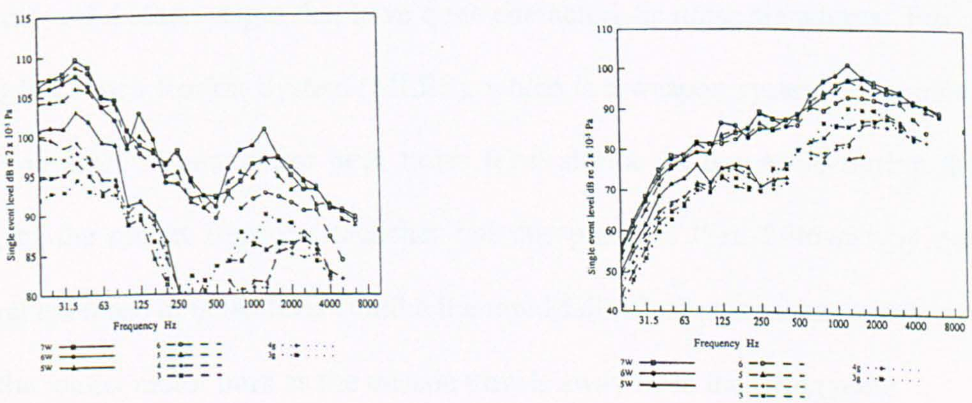
Sensitive receivers sited on the OTA range include farmsteads used for animal husbandry, e.g. sheep, and areas important for wildlife, notably breeding waders such as lapwing, snipe and curlew, and merlin and black grouse. I have prepared an example of noise changes in terms of numbers of noise events and their noise level during a year's exposure to heavy artillery gunfire and the information is shown in Figure 3.7 for different weapons systems and years. The chart provides an at a glance display of the changes to the number of noise events within different noise bands.

The source sound power levels for 'splash' noise (the noise generated by the impact or detonation of the missile) tend to be higher than the initial 155mm gunfire event by between 1 to 8 dB according to the type of shell and its height of detonation. Point detonation shell bursts produce a sound power level of 197 to 200 dB whereas airburst shells range from 201 dB at 1m above ground level to 204 dB at a height of 18m. Therefore, for animals close to an impact area the noise levels are likely to be higher than at locations closer to the guns themselves. The higher the airburst then the noisier the perceived effect is likely to be since attenuating effects due to landform and ground absorption will be less. The use of non high explosive shells (non-HE) or Impact Indicator Rounds (IIR), which contain no HE and provide a smoke burst to allow observers to assess target accuracy, will significantly lessen the potential noise effects.

Artillery noises can also be looked at from the point of view of their tonal characteristics as well as their intensity and fast on-set time. Figure 3.8 (a) shows the average unweighted sound pressure levels measured during the firing of 155mm shells by AS90[315] under different charges ranging from the lowest, 3 Green (3G), up to the highest, 7W. The data represents the average of frequency spectra measurements undertaken at 200-400m around the gun. The greatest amount of sound energy occurs within the lower frequencies, with a peak of 110 dB at 40 Hz.

For noise assessment purposes, noise measurements and predictions are frequently quoted using the A-weighting scale to reflect the frequency response of the human ear - though in the case of artillery gunfire noise it is established practice to measure and assess noise without applying any weighting. There are no established noise standards in the UK for assessing the impact of gunfire noise from heavy artillery systems on sensitive development, however, for noise control purposes the MoD use a criterion of 130 dBLin to represent the onset of significant adverse community response. If the average sound pressure levels from AS90 firing are looked at after applying the A-weighting corrections the results are as in Figure 3.8 (b). The peak of about 100 dB at 1.25 kHz is unaffected but the considerable amount of sound energy within the frequencies below 500 Hz is no longer apparent within the noise data.

Figure 3.8: Comparison of linear and A-weighted third octave band frequency measurements during AS90 gunfire at different charge weights[315]



(a) Linear

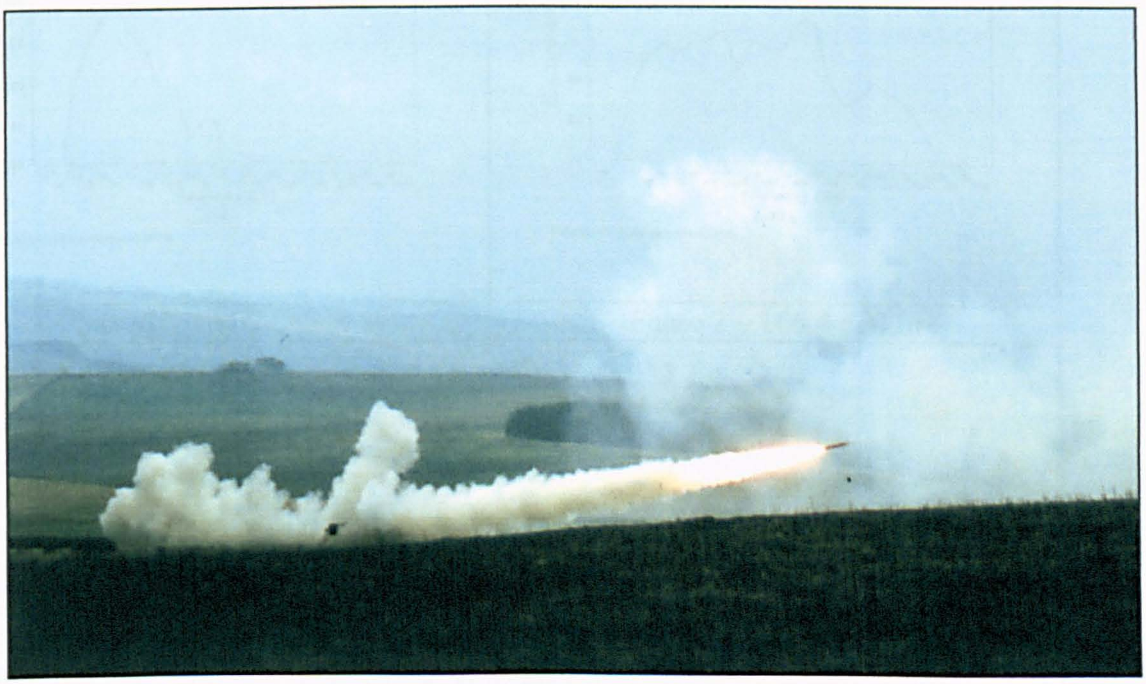
(b) A-Weighted

The loss of the sound energy below 500 Hz may not be significant when making assessments relative to the frequency response of the human ear since this has evolved to be most sensitive to frequencies between 1 to 5 kHz; for instance the primary resonant frequency of the average human ear is 2.6 kHz. The peak sensitivities also coincide with the speech frequency bands, 500 Hz to 4 kHz. However, for animals that have different auditory sensitivities, sound energy in the lower frequencies may take on a greater significance, in which case linear rather than A-weighted noise levels will be more appropriate for assessing noise impacts. All vertebrates have a basic structure and mechanism of hearing similar to that found within Man (except fish, and snakes and lizards that do not possess an external ear), although there are variations between species, which lead to different auditory sensitivities. These issues have been discussed in Section 2.2.

In contrast to the relatively short overall duration of noise from individual gunfire events (i.e. either the firing of the shell from the muzzle or the explosion of the shell some distance away), rocket noise is more complex in that it encompasses a number of different and distinct stages that have quite characteristic noise signatures. Firing of the Multiple Launch Rocket System (MLRS), which is a weapon system comparable to the AS90, produces a maximum peak noise level similar to the AS90 during the initial firing of the rocket from the launcher but this phase is then followed by periods of gradual decrease in noise level (unlike the rapid fall-off of noise from AS90) associated with the rocket motor burn as the missile travels away from the firing point.

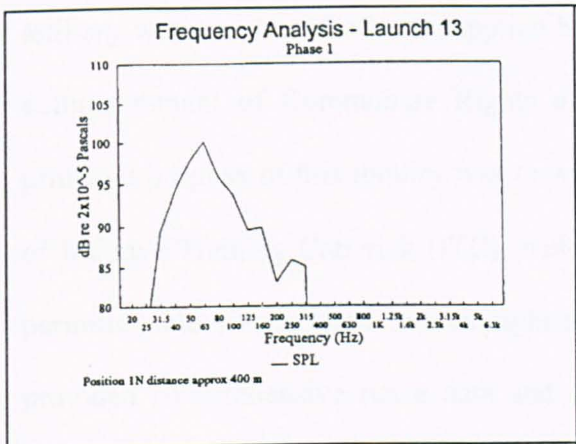
Unlike a shell projectile that will only generate some aerodynamic noise whilst passing overhead, the rocket will also produce noise at ground level whilst the rocket fuel is being combusted within the rocket motor. The current generation of MLRS rockets, the M28 and the Reduced Range Practice Rocket (RRPR), are both supersonic, having Mach speeds of 2.1 and 1.1 respectively, and travel at speeds of 714 and 377 m/s at heights above ground level of 600 and 250m respectively. On this basis, both rockets will be capable of producing sonic booms and the footprints for these will respectively be about 4 and 2 km from the rocket trajectory. Therefore, unlike the shell projectile, rockets have the potential to generate high levels of tonal noise as well as sonic booms/ high air overpressures over large tracts of land between the launch and impact points.

Figure 3.9: Firing of MLRS rocket at the Otterburn Training Area, Northumberland National Park. The rocket trajectory is close to ground and its startle effect causes birds to take flight close to the rocket.

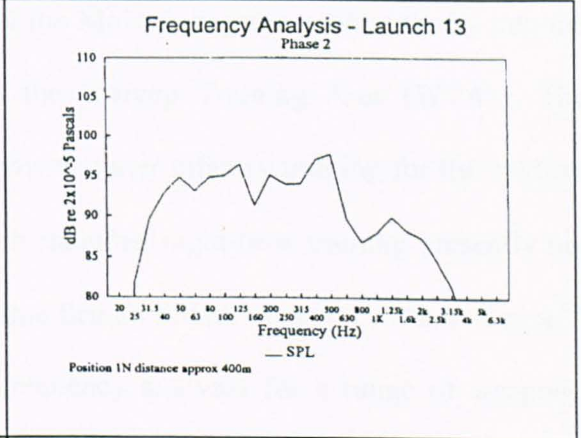


Frequency analysis of the phases associated with the firing of MLRS rockets is shown in Figure 3.10. Measurements were undertaken at 400m to the right of the launcher, with each phase being separated by approximately 0.5 seconds. The point of firing of the missile is similar to the firing of 155 mm shells in that the bulk of the sound energy arises in the low frequency bands - in the region of 63 Hz for MLRS compared to 40 Hz for AS90. However, the firing of 155 mm shells also includes some higher frequency noise of a lower intensity, unlike MLRS. The subsequent phases of MLRS include more broadband noises.

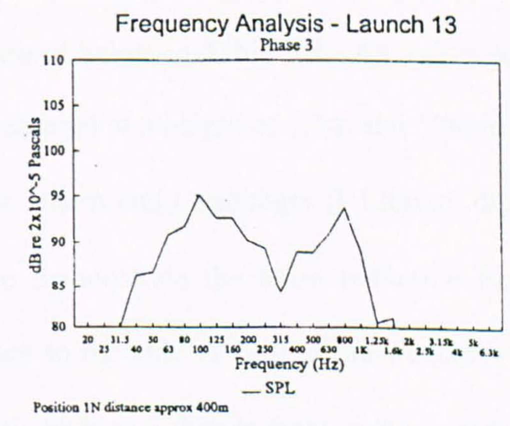
Figure 3.10: Frequency analysis of noise level recorded at 400m during different phases of firing a rocket from a MLRS[315]



Phase 1 – 104.5 dBLin



Phase 2 – 106.4 dBLin



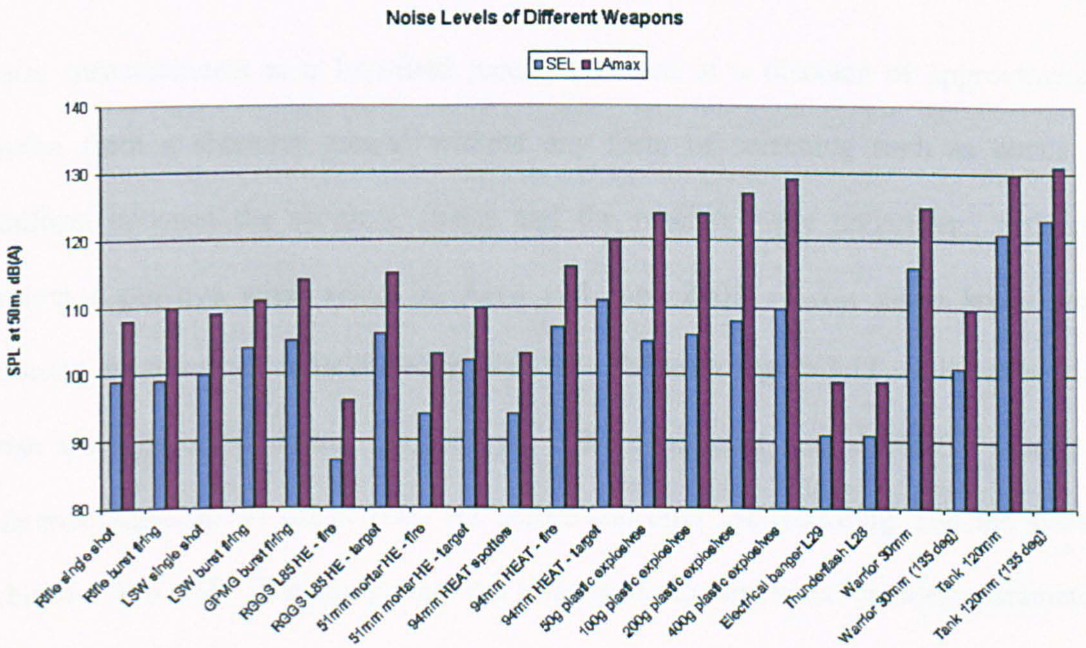
Phase 3 – 102.7 dBLin

It is likely that helicopter rocket launches comprise similar frequency components but there does not appear to be any published data relating to noise levels from helicopter missiles and their consequent noise levels at ground level. The Westland Apache will be fitted with the CRV7 Rocket Weapon System comprising up to two M261 launchers, each containing up to 19 10kg rockets. As for MLRS, the Apache rockets can be fired singly or ripple fired in pairs, fours, eights or the entire launcher pad. The much faster rate of ripple firing from rocket launchers compared to shell fire may elicit different responses in animals, especially since in the Apache's attack (and hence training) mode it will be primarily hovering or travelling slowly close to ground level.

Further information relating to noise levels from a range of light, medium and heavy artillery weapons has also been supplied by the MoD during the public inquiry into the extinguishment of Commoners Rights at the Warcop Training Area (WTA). The principal purpose of this inquiry was to achieve better infantry training for the soldiers of Infantry Training Catterick (ITC), which included night-time training presently not permitted, along with some limited night-time firing of 30mm cannon. The evidence[316] provided comprehensive noise data and frequency analyses for a range of weapons, which enable comparison with other sources and prediction at other locations. The information is summarised below in Table 3.8. All values are sound pressure levels in dB(A) re:$2x10^{-5}$ Pa measured at a height of 1.2m and 50m in front of the firing weapon. In the case of Warrior 30mm and Challenger II 120mm, data is also shown at 135° to the firing direction to demonstrate the noise reduction that for some weapons, e.g. Warrior, can take place to the side or behind the weapon. However, at some angles, noise levels can actually be higher than in front of the weapon (see Challenger at 135°).

Table 3.8: Noise levels measured at 50m from various MoD weapons[316]

Weapon	SEL dB(A)	L_{Amax} dB
Rifle single shot	99	108
Rifle burst firing	99	110
Light Support Weapon (LSW) single shot	100	109
LSW burst firing	104	111
General Purpose Machine Gun (GPMG) burst firing	105	114
Rifle Grenade General Service (RGGS) L85 HE - fire	87	96
RGGS L85 HE - target	106	115
51mm mortar HE - fire	94	103
51mm mortar HE - target	102	110
94mm High Explosive Anti Tank (HEAT) spotters	94	103
94mm HEAT - fire	107	116
94mm HEAT - target	111	120
50g plastic explosive	105	124
100g plastic explosive	106	124
200g plastic explosive	108	127
400g plastic explosive	110	129
Electrical banger L29	91	99
Thunderflash L28	91	99
Warrior 30mm	116	125
Warrior 30mm (135°)	101	110
Challenger Tank 120mm	121	130
Challenger Tank 120mm (135°)	123	131



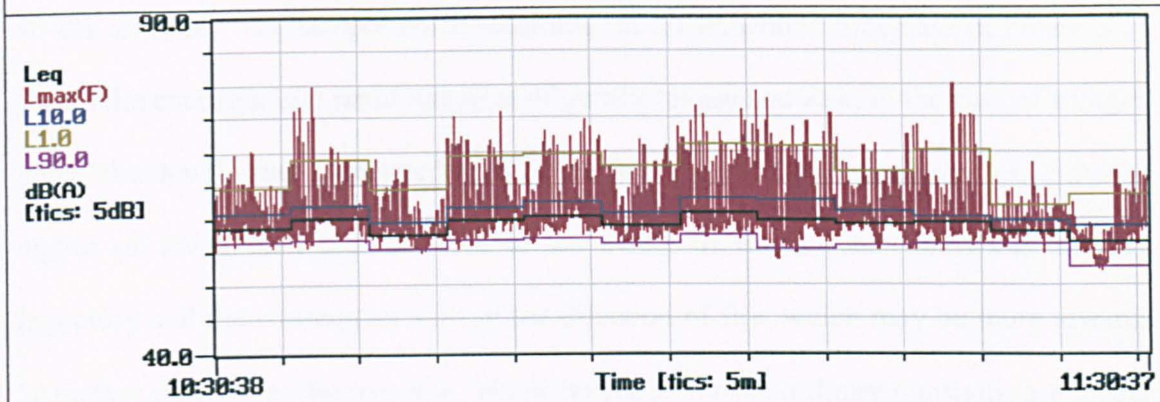
3.5 Comparison of military and civilian impulse noises based on author's data

I have undertaken a number of environmental noise surveys and analyses in order to obtain source noise data for various civilian sources that can subsequently be used for impact assessment purposes at other locations, and this information also allows comparison with military equivalents. The first survey relates to noise from clay target shooting, which takes place outdoors and regularly affects fairly large areas of rural landscapes where various animal populations will be present, and which has a military equivalent in the form of infantry gunfire noise. The effects on human populations are reasonably well defined and guidance from the Chartered Institute of Environmental Health (CIEH) provides noise thresholds to assess the likelihood of adverse comment[317]. These state that annoyance is less likely to occur at a mean shooting noise level (mean SNL) below 55 dB(A), and highly likely to occur at a mean SNL above 65 dB(A). The SNL is derived from the logarithmic average of the highest 25 shots during a 30-minute period, under a positive wind vector.

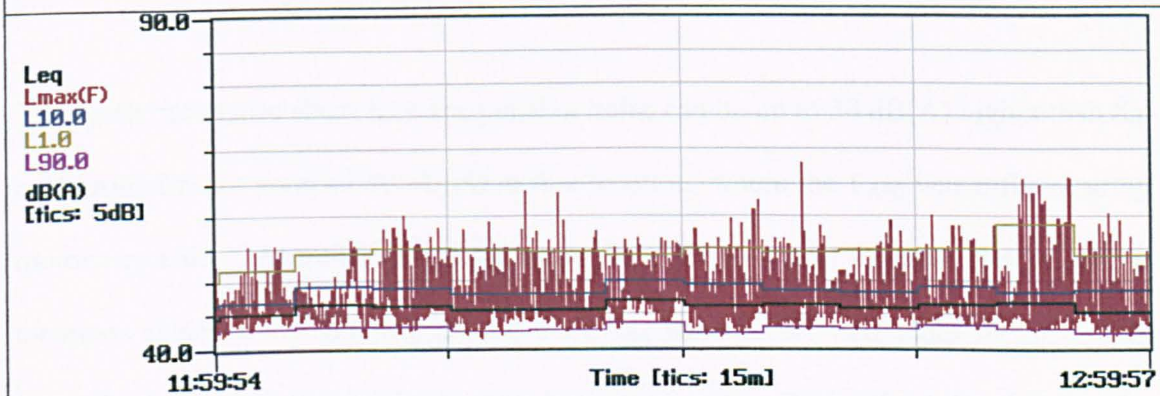
Noise measurements at a free-field receiver located at a distance of approximately 1300m from a shooting ground without any form of screening such as bunds or landform between the shooting stands and the receiver were undertaken with and without a positive wind vector in April and June 2003. L_{Amax} noise levels were recorded every second using the equipment listed beneath Figure 3.11, which shows the noise trace recorded during the surveys. The equipment was calibrated against a reference signal of 94 dB at 1000 Hz before and after the recording, and the system exhibited zero drift. The equipment was also set to monitor statistical noise parameters over 5-minute periods, and the microphone was located at a height of 1.5m above ground level.

Figure 3.11: Maximum noise levels recorded at 1300m from clay target shooting with and without a positive wind vector

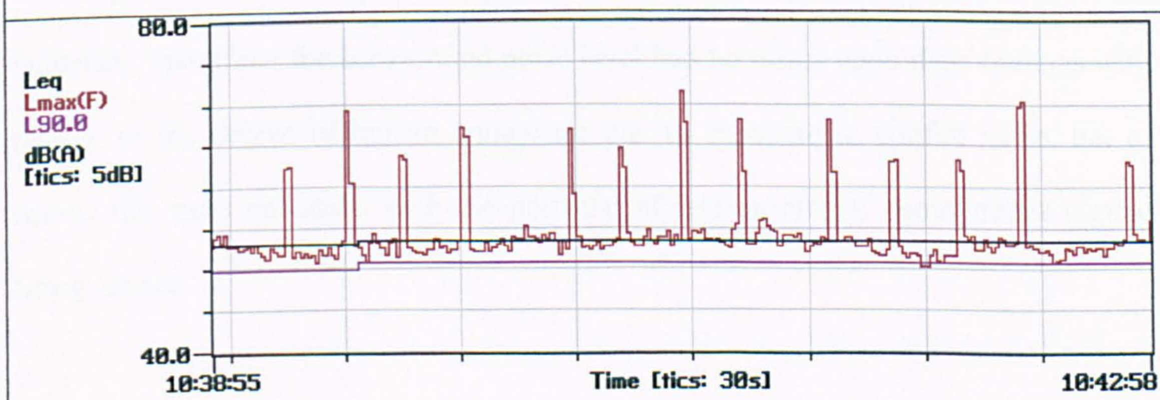
Positive Wind Vector



Without Positive Wind Vector



Sample Noise Trace on Expanded Time Base



Equipment:	CEL-90249 eNVi system hardware with NoiseMaster software; CRL MV 181A Pre-amplifier and cable; MK 224 Precision ½ inch electret condenser microphone with windshield; Psion Series 3c organiser to log and display data; and Larson Davies CA200 acoustic calibrator.

The noise data in Figure 3.11 shows that under a positive wind vector L_{Amax} noise levels of up to 80 dB occurred at 1300m from the shooting ground, therefore, an area of approximately 5.3 km^2 around a shooting ground is likely to experience L_{Amax} levels of 80 dB or more. The sample noise recording on the expanded time base in Figure 3.11 shows the characteristic rapid rise time of gunshot noise and also, in the case of shotgun noise, the double shot associated with twin barrel firing. The second shot can often be higher or lower than the first due to the swing of the shooter following the clay trajectory and the consequent shift in the direction of fire, which may be more towards or further away from the receiver. Noise levels, as for the military gunshots, are louder in front of the gun, i.e. when the direction of fire is towards a receiver.

The noise traces also show how the gunshot noise can be up to 30 dB(A) higher than the background noise level of 50 dB(A) at this location, where the L_{A90} was influenced by motorway noise. At quieter rural locations the difference will be even greater, and at locations closer to the shooting ground the L_{Amax} noise levels, and hence the difference from the background noise level, will be greater still. Research undertaken by the Building Research Establishment (BRE)[318], which formed the basis of the CIEH guidance, found that the background noise level had no effect upon their findings with respect to the degree of human annoyance due to exposure to gunfire noise, but of course this does not assist with the potential effects on animal communities around firing ranges.

During the noise measurements around the clay target shooting ground I observed that **neither dairy cattle in the surrounding fields, nor rabbits in and around the hedgerows, showed any behavioural responses to the gunshots that reached peaks**

of between 70-80 dB L_{Amax}. However, once they became aware of my presence, the rabbits responded by freezing and subsequent bolting. Moreover, young alpacas, which are a gentle, hardy and adaptive species of llama that were newly introduced into an open field at this location, exhibited no adverse behavioural responses from regular weekly exposure to the gunfire noise. This is not to say that physiological responses did not occur as a consequence of this level of exposure, but such responses, if they occurred, were not strong enough to cause observable physical changes or harm. This effect has some relevance with regard to the assessment criteria proposed later in Section 5 and will be discussed further at that time.

The L_{Amax} of 80 dB with a positive wind vector compares to 68 dB without the positive winds. The difference between the two measurements, 12 dB, indicates the changes in noise exposure that can be caused due to changing weather conditions, and this matter is discussed further in Section 4 where similar noise changes due to wind direction are demonstrated for road traffic noise.

In order to compare the shotgun L_{Amax} levels with the artillery noise data presented in Table 3.8, a noise level at 50m needs to be derived, (i.e. on the basis of hemispherical propagation over hard ground, $80 - 20 * \log_{10}(1300/50) = 108$ dB, or $68 - 20 * \log_{10}(1300/50) = 96$ dB). Levels of 96-108 dB at 50m are certainly equivalent to the noise associated with single shot firing of military rifles, light support weapons and rifle grenades (96-109 dB) but, as to be expected, are less than for burst firing of these weapons. However, derivation of noise levels at 50m using data measured at 1300m is likely to underestimate the actual noise level since, in addition to wind gradient effects the data at 1300m will also incorporate factors such as ground attenuation, and air absorption. Therefore, a better comparison can be obtained using actual measurements closer to the point of firing.

Reference noise data for different types of shotgun, cartridges, angles of fire and horizontal angle of the measurement position (i.e. in front of, to the side or behind the firing position) are available from surveys undertaken at the same shooting ground[319]. The free-field measurements were carried out at distances of 50m from each shooting position and the results represent the average from 10 separate shots for each test condition. Of the three guns tested (a Browning 30" with over and under barrels, a Browning 28" over and under, and a Remington 1197 26" 3-shot automatic), there was no significant difference in noise levels and L_{Amax} ranged from 92.5 to 92.9 dB at 50m to the side and 86.8 to 88.5 dB behind the shooter using Game Bore Super XLR 28g cartridges. Various makes and gauges of cartridge were tested and the mean L_{Amax} levels from 24g cartridges were 90.3 dB to the side and 85.6 dB to the rear. In comparison, 28g cartridges produced mean L_{Amax} of 93.2 dB to the side and 87.8 dB to the rear, which indicates that the use of 28g cartridges will produce noise levels approximately 2-3 dB higher than 24g cartridges.

Data relating to the angle of fire in the vertical and horizontal planes for a 30" barrel Browning firing Game Bore Super XLR 28g cartridges is presented in Table 3.9. With regard to the vertical shooting angle, the most important finding is that the mean noise level behind the gun increases by approximately 3 dB when the gun is fired vertically into the air rather than forward. With regard to the horizontal direction of fire, a mean difference of approximately 22 dB exists between noise levels measured directly in front of and directly behind the shooter, and noise levels increase rapidly within the

180° arc in front of the gun, most particularly within the 90° arc centred directly in front of the direction of fire.

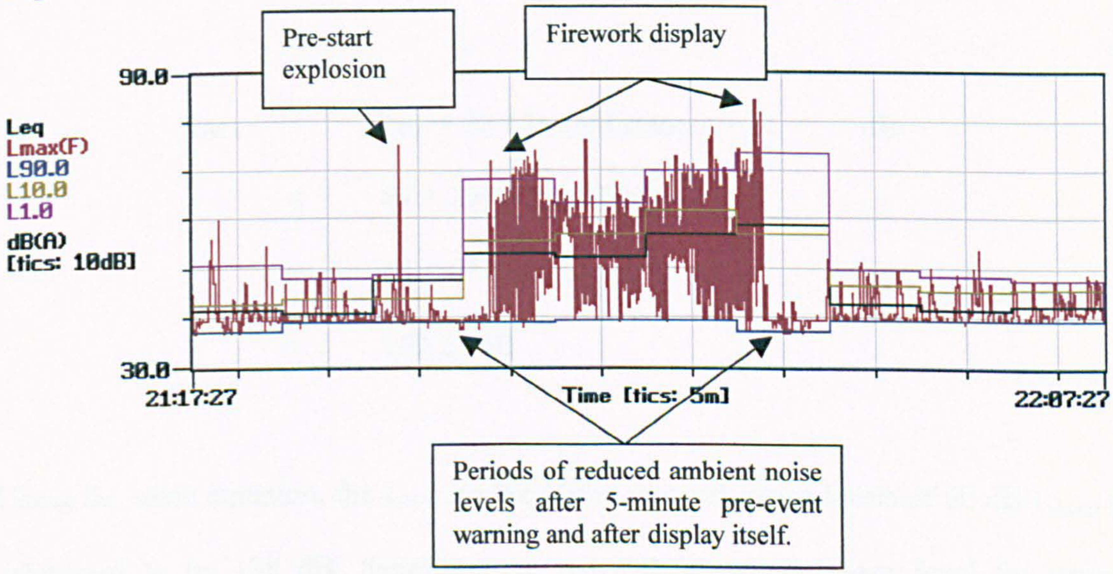
Table 3.9: Mean L_{Amax} noise levels due to clay target shotgun, dB[319]

	Monitoring Position	
Vertical shooting angle	**50m to side of shooter**	**50m behind shooter**
30°	92.9	86.8
Horizontal	91.9	86.8
Vertical	92.4	90.2
Horizontal microphone position	**50m from shooter in test direction**	**50m to side of shooter**
0° (In front)	108.6	92.4
45°	98.5	91.2
90°	-	92.9
135°	89.5	91.3
180° (Behind)	86.8	92.9

The L_{Amax} noise levels measured at 50m ranged from 87 dB behind the shooter to 109 dB directly in front, and the latter is again equivalent to the noise due to single shot firing of military rifles, light support weapons and rifle grenades. Using the data measured at 1,300m, the derived L_{Amax} levels at 50m were 96-108 dB, which are consistent with the data measured at 50m and indicate that any ground or air absorption effects at 1,300m are offset by the wind gradient effects, and that the highest levels measured at the greater distance from the shooting ground will derive from occasions when the measurement position or the receiver is within the 90° arc directly in front of the firing position.

With regard to explosive noise, I undertook noise measurements of civilian explosive equivalents during a public firework display provided by Torbay Council on Monday 23 August 2003. Free-field noise levels were recorded using the equipment listed beneath Figure 3.12, which shows the noise trace during the event. The equipment was calibrated against a reference signal of 94 dB at 1000 Hz before and after the recording, and the system exhibited zero drift. The equipment was set to monitor statistical noise parameters over 5-minute periods and to record L_{Amax} levels every second. The microphone was located at a height of 1.5m above ground level, although this position was also on the side of a valley facing towards the display. The height of the monitoring point above sea level was approximately 75m, which compares to the average height of the firework explosions estimated to be approximately 125m. The horizontal distance between the display and the monitoring point was 2,300m and, due to the relatively high position of the monitoring location, the slant distance also remained 2,300m. The night-time weather conditions were dry, clear and calm.

Figure 3.12: Noise levels measured at 2.3 km from Torbay Regatta fireworks



	Noise Level, dB				
Time	L_{Aeq}	L_{Amax}	L_{A90}	L_{A10}	L_{A01}
2117-2207	52.3	84.3	38.9	50.3	65.7
Equipment:	CEL-90249 eNVi system hardware with NoiseMaster software; CRL MV 181A Pre-amplifier and cable; MK 224 Precision ½ inch electret condenser microphone and windshield; Psion Series 3c organiser to log and display data; and Larson Davies CA200 acoustic calibrator.				

The results show L_{Amax} noise levels at 2,300m from the display of 60 to 84 dB, with $L_{Aeq\ (5\text{-minute})}$ throughout the display itself of 52 to 58 dB. Since at the height of the explosion above ground level (estimated at 125m) sound will undergo spherical propagation, the A-weighted sound power level for the loudest explosion has been calculated as detailed below. Due to the heights of both the source and the receiver, the average height of sound propagation would have been in excess of 100m, therefore, ground attenuation effects would be minimal. However, with the source to receiver distance being in excess of 2 km, air absorption effects would be present within the measurement data and no correction for this is included in the following calculation. In the case of noise from explosions and heavy artillery, which has a significant amount of low frequency energy (near or below 50 Hz), air absorption is not particularly important except at ranges beyond 1 km.

$$
\begin{aligned}
L_{WA} &= L_{PA} + 20 * \log_{10}(\text{distance}) + 11 \quad \text{dB} \\
&= 84 + 20 * \log_{10}(2300) + 11 \\
&= 84 + 67.2 + 11 \\
&= 162.2 \ \text{dB}
\end{aligned}
$$

Using the same equation, the L_{WA} for the lower firework noise levels of 60 dB L_{Amax} is calculated to be 138 dB, therefore, the A-weighted sound power level for typical individual firework explosions within the observed display fell within the range of 138 to 162 dB. Manufacturers' specifications will differ with respect to the amount of explosion required to produce the desired display effect and this may lead to variations above and below these measured levels at other displays.

The measured L_{WA} for AS90 and MLRS during firing was 196 dB, therefore, the measured firework explosions were generally 34 dB or more lower than this source. In order to compare the L_{Amax} levels with the artillery noise data presented in Table 3.8, a noise level at 50m needs to be calculated, (i.e. $162 - 20 * \log_{10}(50) - 11 = 117$ dB, or $138 - 20 * \log_{10}(50) - 11 = 93$ dB). Firework L_{Amax} levels of 93 to 117 dB at 50m indicate that noise levels are likely to be similar to or higher than small arms artillery fire, grenades, mortar fire and thunderflashes, but lower than the high explosive weaponry, which includes tanks firing.

An interesting feature of the noise recording in Figure 3.12 are the periods of reduced ambient noise, which lasted for approximately 5 minutes, after the 5-minute pre-event boom and more particularly after the display itself. Other researchers[181, 320, 321] have found short term responses where vocalisations of mammals, birds and amphibians have ceased following the introduction of a noise into the animal's environment. However, in this case the periods of reduced noise were due to reduced human rather than animal activity.

3.6 Unmanned Aerial Vehicles

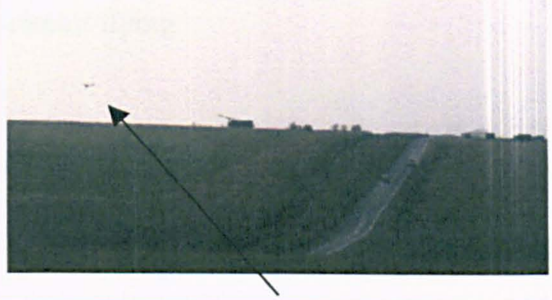
Unmanned aerial vehicles (UAV) act as target acquisition devices for certain weapon systems such as MLRS. They would normally be launched from within a training area and are likely to spend some time in a holding pattern as they observe events on the ground and send information back to their control centre, and at other times will be routed from one target area to another.

The MoD are presently using the Phoenix UAV to provide aerial support for MLRS during training. Phoenix has a wingspan of 18 feet and is 12.3 feet long, and is launched from a vehicle (see Figure 3.13). At the end of its reconnaissance period it parachutes back to ground. Its operating speeds are typically 32 m/s when cruising, with a maximum (dash) speed of 46 m/s, and its noise characteristics are similar to many light aircraft, although its aerial activities can also be likened to model aircraft. It has an operational period of about 5 hours although for training purposes it is likely to be restricted to a maximum of 2 hours flying time at a height of between 700-1000 m. Where more than one Phoenix may be airborne at the same time, vehicles would be separated by at least two kilometres during hand over tasking. The MoD's statement of requirement for Phoenix required that noise from the vehicle should be less than 60 dB(A) when measured at a distance of 1 kilometre.

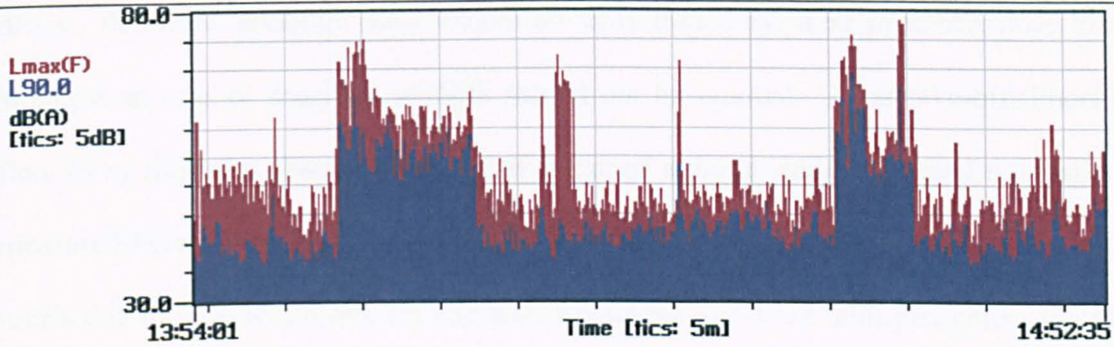
I undertook noise measurements of the launch and subsequent circuit flying of Phoenix during the MoD's demonstration of Phoenix at Salisbury Plain on Tuesday 16 March 1999. Free-field noise levels were recorded using the equipment listed beneath Figure 3.13, which shows the noise traces during the event. The equipment was calibrated against a reference signal of 94 dB at 1000 Hz before and after the recording, and the system exhibited zero drift. The equipment was set to monitor L_{Aeq} and L_{A90} noise levels over successive 10-second periods and to record L_{Amax} levels every second, although only the L_{A90} and L_{Amax} values are displayed in Figure 3.13. The microphone was located at a height of 1.5m above ground level, and weather conditions remained dry and cool but with occasional blustery winds blowing from the demonstration towards the measurement point.

Figure 3.13: Noise levels recorded during launch and subsequent circuit flying of the Phoenix unmanned aerial reconnaissance vehicle at Salisbury Plain

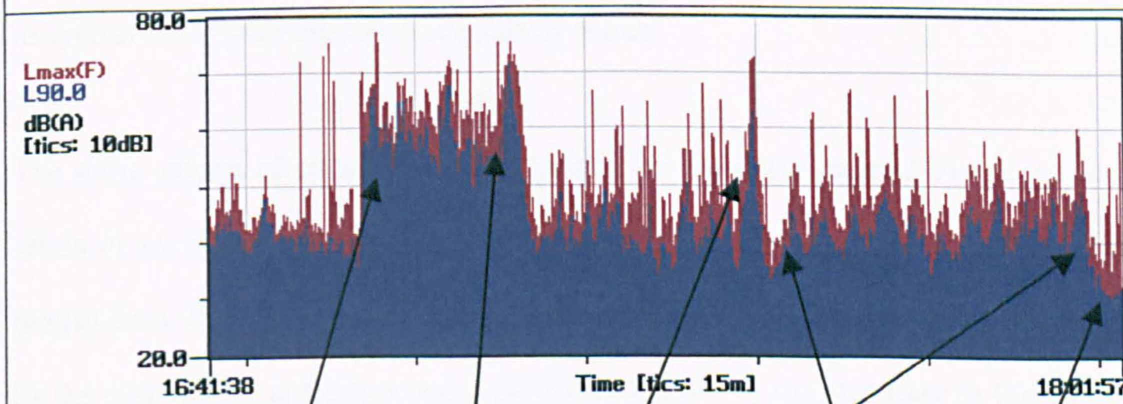
Phoenix on launch pad



Phoenix after take-off



Noise levels during two abortive take-offs



Noise levels from launch and circuit flying

Equipment:	CEL-90249 eNVi system hardware with NoiseMaster software; CRL MV 181A Pre-amplifier and cable; MK 224 Precision ½ inch electret condenser microphone + windshield; Psion Series 3c organiser to log and display data; and Larson Davies CA200 acoustic calibrator.

The first noise trace shows the noise levels during two abortive take-offs, i.e. whilst the Phoenix was sitting on the launcher and occasionally revving its engine. The second trace shows the launch pad noise, with the noise peak due to take-off, followed by various noise levels during altitude gain and circuit flying.

At the measurement distance of 600m from the launcher, noise levels are typically about 60 dB(A) although occasionally peaks of 70-80 dB(A) arise due to variations in engine pitch and wind conditions. During take-off, noise levels rise to approximately 75 dB(A), therefore, although these events are only transitory, their presence close to or amongst an area of sensitive wildlife should not be ignored. After take-off, Phoenix flew away from the observation point as it gained altitude, and noise level fluctuations measured between about 1710 and 1732 hours on the second noise trace reflect noise levels due to vehicle movements and shell bursts etc. At 1732 until just before the end of the noise trace, Phoenix entered a phase of circuit flying, which is representative of its typical activity during target acquisition duties.

The noise effects of circuit flying are evident on the noise trace of Figure 3.13 as a series of 11 cyclical peaks during which L_{Amax} noise levels due to Phoenix typically ranged from 35 to 55 dB(A). The effect of constant noise from Phoenix is demonstrated by the cyclical rise in background noise level (denoted by the blue trace in Figure 3.13) as Phoenix performed each flying circuit. The minimum and maximum noise levels for each circuit correspond to separation distances of approximately 1,700 and 5,000m measured from Phoenix's flight plan during the demonstration. Background noise levels within wildlife areas such as National Parks can be very low, for example the L_{A90} recorded at the end of the noise measurements in Figure 3.13, after Phoenix had flown off to its recovery point, was approximately 30 dB. Therefore, UAVs have the potential to raise background noise levels by up to 25 dB(A) or more subject to their position relative to a receiver at ground level, which, although it is unlikely to induce the same degree of physiological or behavioural responses generated by the loud military noises, may have some effect on the way animals are able to perceive other noises within their natural habitat. For example, since UAVs can be present for up to 5 hours, and can also be used at night, their noise could have some bearing on a predator's ability to detect its prey, or conversely for the prey to detect and avoid the predator.

As a point of comparison, the Department of the Environment Code of Practice[322] for the minimisation of noise from model aircraft, recommends that except for competitive flying, no model should be operated which gives a noise measurement at 7 metres of more than 82 dB(A). (At an equivalent distance Phoenix would produce a noise level of approximately 103 dB(A), which is 16 dB higher than for model aircraft.) Section 8.2 of the Code states "Most animals, whether wild or domesticated, are probably not unduly worried by model aircraft noise; it can however be distressing to some at sensitive times, for example to mares when in foal, sheep at lambing time or birds in the nesting season."

The response of animals to model aircraft may be partly influenced by the relatively high speeds and the consequent rapid change in noise level as aircraft approach a receiver, especially during low level dives. The ability of animals to evaluate rate of change of noise to determine the proximity of a potential threat is often a point of uncertainty. So far as UAVs are concerned, although their noise levels are lower than most other military sources they are still equivalent to or higher than civilian analogues that are acknowledged as having the potential to adversely affect animals.

3.7 Shipping and Sonar

Underwater issues are considered in Appendix IV.

3.7 Summary

The conclusion of this comparison of military and civilian sources is that there are many similarities between the two that enable documented responses from one to be applied, with due caution, to the other. The main difference between the two is the often much larger power sources associated with military equipment, which is necessary to make them faster and more manoeuvrable through tougher terrain and to give them the ability to carry much heavier loads such as armaments and cargo etc. The direct consequence of more power is generally more noise and often much faster rates of noise on-set. The rapidity of noise on-set is a possible major cause of startle within some animals, in which case fast military sources may have a greater potential to disturb animals than civilian sources. Nevertheless, the overall conclusion is that the documented responses of animals to specific military or civilian sources can be used against equivalent sources, but allowance may need to be made for the likely difference in source noise levels and hence degree of response.

4. IMPORTANT FACTORS WHEN ASSESSING THE ENVIRONMENTAL IMPACT OF NOISE ON ANIMALS

This chapter discusses matters that are likely to affect an animal's exposure or response to levels of environmental noise, with a view to identifying factors that will be of importance during an impact assessment. Factors are illustrated by additional examples of animal responses that supplement the information presented in Chapter 2. The routine methods for monitoring and assessing noise levels relative to human exposure may not necessarily be appropriate for environmental assessments (EA) on animals. The key factors that I have identified, not in any order of priority, are as follows:

- hearing sensitivity of exposed animals;
- habitat characteristics and effects on noise transmission;
- screening effects due to terrain;
- noise exposure at the animal position;
- background noise level;
- source characteristics;

- suitability of monitoring equipment and microphones;
- behavioural patterns;
- meteorological sources and effects;
- seasonal and diurnal rhythms; and
- energy expenditure.

4.1 Hearing Sensitivity

The literature review of animal responses shows the broad spread of effects that noise may or may not have on an animal population. In some circumstances the results show no significant adverse effects on animals whereas others show adverse and sometimes dire consequences for animals. Variations can occur within the same species and the same population and for the same type of noise exposure. However, what is evident from the research is that when a species has particularly sensitive hearing in a certain frequency range, and when the noise from the source contains the same or similar frequencies, the risk of an adverse impact is much greater and the consequences for the exposed animal are likely to be much more severe and occasionally life threatening. The ranges of hearing sensitivities applicable to different animals have been quantified in Chapter 2 and can be used to establish when conflicts are likely to arise.

One of the best examples of an animal's use of tonal components within its daily activities, which can be strongly affected by man's activities to the detriment of the animal, can be found in the kangaroo rat (*Dipodomys* spp.). Kangaroo rats are solitary, desert rodents that are active during the night. They communicate by means of drumming their feet on the ground, which creates vibrations within the ground and in the air. In the open, desert environment, where there will be few other ambient noise sources, low frequency sounds in particular can travel significant distances and the kangaroo rat uses the sounds of its foot drumming to influence spacing, competition and predator defence. With food being scarce in desert environments, competition between neighbouring animals for food caches will be high and caches are protected by foot drumming and chasing. These behavioural characteristics are present within not only the kangaroo rats of North America but also gerbils from North and South Africa and Asia. All of these rodents have evolved to be sensitive to the low frequency vibrations transmitted by foot drumming via both the air and seismically through the ground.

Different species of kangaroo rat have evolved different signals by grouping individual footdrums into bursts or footrolls of differing lengths and sequences. For example, the desert kangaroo rat has a simple pattern of single drums at a rate of about 4 drums/second; the giant kangaroo rat drums very long footrolls that can average over 100 drums at a rate of 18 drums/second; and the banner tailed rat varies the number of individual drums within the first footroll, and the number of subsequent footrolls in a sequence, to generate different patterns[323]. The messages from the different types of signals are assumed to denote territorial ownership, the presence and location of individuals within the community, and the competitive superiority of individuals.

Although low frequency transmission and detection plays an important part in the communication between neighbouring kangaroo rats, at first glance it seems unlikely that any extreme adverse impact could arise due to extraneous noise, especially since non-audible 'chasing' as well as 'drumming' is used to maintain territories, and localised noise effects should affect all individuals within an area rather than just one or some of the animals. This suggests that the detection of low frequency sounds may have other important uses such as the detection of predators.

In desert/scrub areas typically used for ORV use, background noise levels can be very low, which will increase the area over which the ORV noise, in particular the low frequency sounds, will be audible. For instance background noise levels may typically be 30 dB or lower in remote areas, and field measurements and modelling have shown one production trail bike could be audible for a distance of 3 km in open country (no screening due to landform), and 10 trail bikes could be audible for 4 km[324]. The speed with which such vehicles can cross the terrain means that a large area of land, and hence possible animal populations, can be covered during a single excursion.

In addition to specific hearing capabilities, some species may have evolved mechanisms for using acoustic signals in other ways. For example, Ambient Noise Imaging (ANI) has been postulated as a means by which some marine mammals may be able to detect other animals (prey) by sensing an acoustic image generated by the noise emitted from them[325]. Some documented reports lend support to this proposition in that when eye cups were applied to a captive Atlantic bottlenose dolphin (*Tursiops truncatus*) that had never encountered live fish during its several years of captivity, it was able to follow and catch a fish in five sequential tests without any sound being recorded either by the listening devices attached to the dolphin's head or by other sensors suspended within the water. A similar report exists for the grey seal (*Haliocherus*) and it seems possible that such animals may use a biological sense equivalent to ANI when their target is a good resonator such as a fish with a swim bladder. Clearly, the presence of continual or regular noise signals within a feeding area of such animals might then interfere with an animal's ability to successfully hunt and feed. This illustrates the importance of knowing all of the ways in which an animal uses noise to its advantage.

4.2 Sound Propagation and Habitat Characteristics

Sound transmitted between the noise source and the receiver location may be affected by up to five principal factors, which include the spherical spreading of sound, absorption, reflection effects, refraction and diffraction or scattering[326]. The significance of these factors on receiver noise levels will vary from one site to another according to the features within the habitat, e.g. desert, woodland, grassland, shrub, forest, snow and water. A further important factor will be the degree of any screening arising from the local topography, e.g. hills, gorges or indeed individual rocks/boulders, screening provided by dense vegetation, or screening provided by burrows beneath the ground. Caves may also provide a significant degree of screening subject to the orientation of the cave opening relative to the noise source, the size of the opening, and the distance that an occupying animal is back from the entrance.

In any given situation where an animal is exposed to unnatural sounds, the total attenuation of sound between the source and the receiver, excluding screening effects that are discussed later, will depend on the factors described below, not all of which will apply in every situation. The amount of attenuation provided by each factor, or indeed noise enhancement in some cases, may also vary from one location to another or even may vary along the sound transmission pathway. In addition, on some days convection currents and turbulent eddies may be present, which will further cause the sound pressure and phase of the signal to fluctuate considerably within short distances. Noise variations of 5 dB or more are likely to arise over short periods of time during both the day and the night as an animal moves around its territory, and these changes will be greater than the change that would arise due to an animal walking towards a distant noise source. For these reasons, it will be difficult for an animal to judge the proximity of a noise source (and hence the danger) just by reference to the absolute noise level received. This would support the hypothesis that they more often look to the rate of change of noise as a means of determining the degree of threat. The main factors affecting the received noise level are summarised below.

Spherical Spreading

Spherical spreading, which takes account of the attenuation of noise over distance, will arise in every situation where the animal is separated from the noise source. Where sound is radiated from the noise source evenly in all directions, the attenuation rate will be 6 dB per doubling of distance. In the case of cylindrical spreading of noise, which arises in the case of line sources such as road traffic flows or the confinement of low frequency transmissions within water boundary layers, the decrease is only 3 dB/doubling of distance. In extreme situations where sounds may be reflected without loss within a channel, the attenuation may approach 0 dB. However, in most natural situations, the environment is unlikely to be totally confining and reflective to the extent that there would be no attenuation of sound with distance.

Absorption

The absorption of sound energy covers its conversion to heat energy within the air or transference of sound energy into another medium. The absorption of sound within the air is a complex function of several processes that are dependent on the air temperature, relative humidity and sound frequency. The latter is the main factor, with the most significant amounts of attenuation occurring at higher frequencies. However, in tropical rain forests where the air is very hot and humid, the attenuation can be very large to the extent that it can significantly diminish bat echolocation to one or two metres[327]. Similar unfavourable conditions for bats in the UK tend to arise only in foggy weather[328].

The absorption of sound within water is much less than that in air, by a factor of approximately 20, although it shows the same increase with increasing frequency[329]. The attenuation at low frequencies is so small that the detection of low frequencies over hundreds of kilometres is a possible means of communication for some species. The same principle is used by the ATOC surveys reviewed in Appendix IV. Even high frequency sounds experience only a little attenuation within the hearing ranges used by many marine mammals, which makes the use of echolocation difficult for some and may explain why Ambient Noise Imaging may be used as a means of visualisation by marine mammals.

Reflections

Reflections arise where sound strikes a different medium possessing a different acoustic impedance. Acoustic impedance is defined as the density of the medium multiplied by the velocity of sound within the medium. The main reflective surfaces for animal populations are reflections from the ground or at air-water or water-air interfaces. In the latter situations, less than 1/1000 of the incident sound energy is transmitted to the other medium, which explains why noise from low flying aircraft or from sonic booms has limited effect on aquatic life.

In the case of ground reflections, many smaller animals will be extremely close to the reflecting surface and the incident noise may rarely strike the surface perpendicularly. Where noise is travelling across the ground from a distant low level source, it will experience only a grazing angle of incidence with the ground, for which the actual amount of reflection may be insignificant. However, it is important to note that complex situations can arise. For example, ground reflection (or excess attenuation due to ground effect) is frequency dependent, and if the ground is hard (as it typically is at low frequencies) even at grazing incidence there is reflection and the sound level is increased by the presence of the ground. In some situations, which will depend on the relative locations of the source and receiver, direct and reflected sound waves may interact, which can lead to enhancement due to in-phase signals or destruction due to out-of-phase signals.

Refraction

Refraction or deflection of sound waves arises as a consequence of changes to sound velocity, which are dependent on temperature and density of the medium, and, in the case of propagation through the air, the wind speed itself. Water currents are generally too slow to have any significant refraction effects through water. Temperature, humidity and wind speeds often vary with height above ground level and also above different types of terrain or vegetation. During warm sunny weather, temperature often decreases with height above ground and the velocity of sound will then also decrease, causing sound waves to deflect upwards leaving a noise shadow at a certain distance from the source.

If the receiver is upwind, the wind gradient will further increase the upward deflection of sound causing an even greater shadow zone, which may cause transmitted noise levels to be reduced by as much as 25 dB in the upwind direction. In contrast, on clear nights the temperature may increase with height to a maximum after which it decreases, i.e. a temperature inversion. At such times the sound waves will be 'trapped' within a layer close to the ground, thereby resulting in sounds being heard at greater distances from a source than occur during the day. Sound will, therefore, attenuate less than expected due to spherical spreading alone, which means that the excess attenuation is actually a negative value. Animals that vocalise at such times should be heard over greater distances, and equally, noise generated at such times will travel further and potentially affect more distant animal communities. Monkeys in particular vocalise at a time when temperature inversions will enhance long distance communication. Frogs also often call at times when excess attenuation is likely to be reduced by temperature inversions, but it is not certain whether this is an adaptation or coincidence[330]. During early morning, the temperature changes can be more dramatic and closer to the ground, thereby channelling sounds to even greater distances.

Changes in sound velocity likewise occur within water but are dependent on temperature, hydrostatic pressure and salinity. A decrease in temperature with increasing depth in tropical and temperate waters causes the sound velocity to decrease to a minimum at 1-2 km from the surface. At greater depths the velocity increases due to the higher hydrostatic pressure. The temperature does not change as much within colder arctic waters and the velocity is largely determined by hydrostatic pressure.

Diffraction

In contrast to reflection, which involves sound being redirected along a specific direction after hitting a fairly large surface, diffraction involves the scattering of sound energy into a multitude of directions after hitting objects or surfaces. As a guide, if the size of the object is much smaller than the wavelength of the incident sound it will have little effect upon the sound wave but if it is somewhat bigger than or of a similar size as the largest incident wavelength it will cause diffraction. Diffraction will also occur around the head of each animal and is one of the mechanisms used in the directionality of hearing. Diffraction will be important as sound waves pass through vegetation, where objects such as leaves, branches and twigs may often be similar in size to the wavelength of sounds.

4.2.1 Vegetative Effects

Vegetation will not only affect sound transmission due to diffraction effects but also due to the variation of the microclimate within the vegetation, e.g. the mere presence of the vegetation will alter the temperature, humidity and wind turbulence compared to the same land without the vegetation. In effect, sound transmission through vegetation will be affected by diffraction or multiple scattering, microclimate changes and finally absorption, and it is difficult to quantify the contribution of each to the overall noise attenuation. If one assumes that multiple scattering is the dominant factor, then the excess attenuation over the normal spherical spreading of noise is likely to amount to a further 6 dB, making a total of 12 dB/doubling of distance. If absorption is assumed to be the dominant factor, then the excess attenuation will be a factor based on the depth of vegetation, i.e. dB/m. Most research suggests an attenuation of between 10-30 dB/100m due to absorption but the actual level will be strongly dependent on the type and density of the vegetation, with the maximum attenuation occurring at higher frequencies.

The Transport and Road Research Laboratory looked at the use of vegetation for screening traffic noise, by reviewing past research and also undertaking measurements across different habitat types[331]. Their measured findings are summarised in Table 4.1 for different habitat types and show an attenuation for broadband traffic noise of up to 9 dB.

Table 4.1: Attenuation of traffic noise due to different types of vegetation[331]

Vegetation	Attenuation/dd over 30m, dB	
	Total	Maximum(1)
Grass	5.4	7.3
Deciduous woods	6.2	7.7
Rhododendron, bracken and birch	6.4	7.3
Rhododendron and pines	6.8	9.3
Gorse and brambles	6.5	7.6
Dense spruce	7.4	8.5

Note: (1) The highest attenuation rate for any pair of microphones over the 30m survey distance.

Various studies have looked at the attenuation of sound travelling through vegetation, and the amount of sound absorbed is much greater from trees in leaf than when bare, and broadleaf trees provide greater absorption than conifers. Bare tree trunks and branches tend to cause sound attenuation due to scattering sound rather than absorption. One study[332] provides an equation for the attenuation based on the surface area density, F m^2 (the total surface area of leaves per unit volume), the depth of trees, L m, and a frequency-absorption factor, G. The factor G is dependent on the size and shape of leaves (increasing with larger sizes of leaves), and is typically approximately 0.001-

0.002. As long as the minimum value of L is above 0.3m and the frequency, f, is greater than 100 Hz the sound attenuation through absorption is quoted as follows:

$$\text{Attenuation} = -10 \log (1-(GFLf^{0.5})/8)$$

However, although the calculated attenuation agrees reasonably well with measured attenuation over small experimental areas and volumes, the equation does not always work when applied to situations approximating full scale circumstances in the natural environment, e.g. large and deep tree belts.

The rate at which sound decays in different habitat types is important with respect to communication within certain species such as insects and birds. Equally, the way in which the habitat affects the propagation of sound from a noise source will be important in terms of the absolute level perceived by each animal and possible interference with communication or detection of predators and prey. Factors such as temperature, relative humidity, wind speed, density of vegetation, foliage size, position of the sender and receiver, and the carrier frequency of the sound all affect the excess attenuation of sound between the sender and the receiver compared to the attenuation due to distance alone.

A study of sound propagation in different natural environments[333] looked at the attenuation rates at different heights above ground level over a plain summer meadow, the same meadow covered with approximately 15cm of snow, a desert dry lake and a shrub covered desert area. The results showed that with the exception of the summer meadow, a substantial amount of excess attenuation between 1-7 kHz occurs at ground level compared to heights of 0.7m or more. The snow covered surface provided the greatest amount of attenuation but it is not clear why the summer meadow did not provide a comparable degree of attenuation closer to the ground when its surface and vegetation should provide more absorption and scattering of sound than the harder desert surfaces.

Due to the small size of many insects, they can only produce sounds of reasonable loudness in the high sonic or ultrasonic frequency range[120]. High frequency sounds, in particular at 20 kHz, attenuate much more rapidly to the extent that the decay rate tends to be 12 dB per doubling of distance rather than the 6 dB due to spherical spreading alone. Multiple scattering within the vegetation represents the main source of excess attenuation of high frequency sounds. At frequencies greater than 20 kHz, other sources of attenuation add to that due to spherical spreading and multiple scattering to increase attenuation above 12 dB/doubling of distance. For example, for a carrier frequency of 40 kHz, the excess attenuation can reach more than 30 dB at a distance of 10m, compared to values of 12 dB for 10 kHz sounds and 3 dB for 5 kHz[120].

Due to the high level of excess attenuation of high frequency sounds produced by animals such as insects, they use appropriate behavioural strategies to maximise their ability to send and receive acoustic signals between individuals. This mainly means that better communication will take place if insects call and listen from on top of the vegetation. The same situation is observed with respect to bird song. However, in the case of certain insect species, background noise due to the singing of other members of the species in the locality can have a dramatic influence on the behaviour and maximum hearing distance. In such cases, although an intruding noise might be relatively high, it might, at the receiver position, be exceeded by noise from other members of the species.

Studies of insect communication show that sound attenuation greater than that expected due to spherical spreading will increase with increasing frequency of the sound, increasing distance between sender and receiver, and also decreasing height within the vegetation. Similar results have been observed from avian studies[334] and both conclude that amplitude modulated song patterns using broadband carrier signals, are more effective for long-range communications than pure tone signals, at least in open habitats. In the same way, amplitude modulated broadband noise from a new noise source will be able to travel further to distant animal communities.

However, although some birds and other animals may call/sing from a high perch in order to maximise the transmission distance, this is not always the case, and the circumstances are not always the same between sexes of the same species, which could lead to a failure to fully assess the implications of an intruding noise. In the case of the blackbird (*Turdus merula*) in woodland habitats, it would appear that the male climbs upwards to improve its ability to hear responses to its songs, which is important during advertising and challenging. In contrast, the females usually hide in the undergrowth, which results in a different sensitivity to song parameters affected by degradation of sound through the vegetation. The females seem to rely less on the upper frequency bands to discriminate species and disregard aspects of amplitude modulation and duration[115].

The blackbird song comprises a lower frequency element (1.5-3 kHz) followed by a broadband 'twitter' (1.5-8 kHz). The amplitude functions of the lower frequency part of the song are 33-57% more blurred when received by the females at 0.2-3m above the ground than when received by males at 9m above the ground. Since, in the blackbird, distinct differences are present between the male and female's use of sounds relative to their typical position with their environment, this illustrates the possible need to assess an intruding noise's impact not necessarily just on the species but occasionally on the sexes within a species.

The relationships between vegetation, noise attenuation and animal communication raise a matter that is not normally considered by the EA process, namely the possibility that newly introduced landscaping may affect the noise climate for existing animal communities or new communities that may eventually inhabit the site. Landscaping is often raised as a means of limiting noise impacts on neighbouring human communities, although the effect is more often a subjective impression than one that achieves substantial noise reduction. Earthmounds and associated landscaping to screen a noise source may be viewed as a means of creating new habitats and hence ecological enhancement. However, this approach will need to ensure that the habitats being created attract species tolerant of the noise level within the landscape zone.

Studies into the reflection effects of deciduous plant leaves[335] have shown that leaf dimension and leaf mass are key factors. Reflections occur least at low frequencies and increase with high frequencies, when the wavelength is less than the leaf radius. Therefore, plants with large leaves should be preferred when using vegetation as a means of noise control. Where models have been used to investigate sound transmission through vegetation[336], these have shown that not only does foliage act as a good noise filter for high frequency sounds, but also that foliage can act as an amplifier for mid-range frequencies, which is important for animal vocalisation and communication. The filtering effects are again dependent mainly on the maximum size of the plant leaves. Measurements of attenuation rates through different UK woodlands[337] (comprising various mixes of Norway spruce, oak, red cedar and Corsican pine) have demonstrated a characteristic peak in excess attenuation below 500 Hz due to ground effects, a dip in attenuation at midfrequencies around 1 kHz, followed by increasing attenuation above 1 kHz due to the scattering provided by tree trunks and branches and the scattering and absorption provided by foliage.

4.3 Screening

The amount of noise attenuation provided by a screening obstacle is primarily a function of the height of the screen relative to the heights of the source and the receiver, and the distances of the screen from the source and the receiver. These factors result in a path difference, δ, which is the difference between the straight line distance from source to receiver without the screen and the longer distance when sound has to travel over or around a screen. However, the attenuation is also dependent on the frequency of the sound since lower frequency sounds have a larger wavelength, which will result in increasing amounts of sound energy deflecting over or around the barrier.

Most barrier calculation methods, for example the Calculation of Road Traffic Noise[338] (CRTN), provide a composite attenuation value that takes account of the known frequency spectrum of traffic noise and the varying attenuation rates across this spectrum. This approach is acceptable where the source is road traffic noise and the assessment relates to impacts on human populations using the A-weighted scale, however, it may not be appropriate for other sources nor when the assessment applies to animals and may need to be specific to a particular hearing frequency. In the latter case, the barrier attenuation can be determined using the frequency dependent Fresnel number, N, which is defined as follows:

	N	=	$2(\delta/\lambda)$
Where	δ	=	path length difference, in metres; and
	λ	=	wavelength of sound in air, in metres.

A suitable method for determining the insertion loss (IL) provided by a barrier at different frequencies is provided by the following equation[339], which applies to a single noise source at its closest point to a receiver:

Insertion Loss, IL = $5 + 20\log(\sqrt{2\pi N}/\tanh\sqrt{2\pi N})$ dB (4.1)

for $-0.2<N<12.5$, or IL = 24 dB for $N>12.5$

If one considers a situation of an animal positioned 120m from, say, a helicopter hovering at 10m above ground level, with a screening obstacle 5m high at 20m from the animal whose ear is 0.2m above ground, the barrier attenuation calculated using a composite procedure such as CRTN would be -11.7 dB for a path difference of 0.2934. In contrast, the attenuation calculated for some specific frequencies using the Fresnel number would be as shown in Table 4.2.

Table 4.2: Barrier insertion losses calculated for some selected frequencies using equation 4.1

Frequency, Hz	20	1000	5000
Wavelength, λ m	17.2	0.344	0.0688
Fresnel number, N	0.034	1.706	8.529
Insertion Loss, IL dB	5.6	15.3	22.3

The information in Table 4.2 demonstrates the substantially greater attenuation that will occur for higher frequency sounds, and conversely, shows that barriers are less effective against low frequency sounds, when they will provide a significantly smaller insertion loss compared to values calculated using a composite method. For the above example, the screening obstacle would need to be 18m high in order to provide an attenuation at 20 Hz equivalent to that calculated using the CRTN method, or 28m high to provide an attenuation at 20 Hz equivalent to that provide by the 5m screen for sounds at 1,000 Hz. This difference illustrates the importance, when noise screens are present, of undertaking an assessment that properly takes account of the frequency sensitivity of the animal, the frequency of the sound source and the frequency performance of screening obstacles such as barriers, buildings or landforms.

4.4 Noise Level at the Animal Position

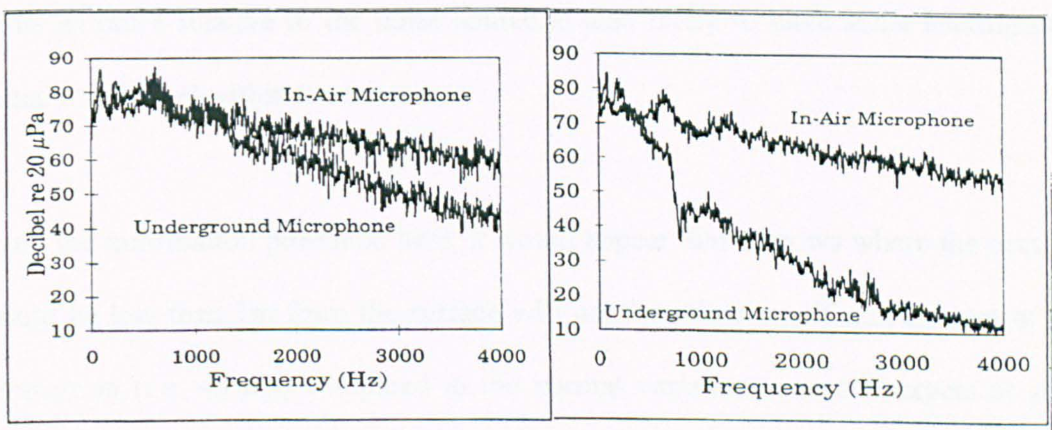
The position of an animal relative to a noise source is likely to be much more varied than is the case for Man. For instance animals may be on the ground, in the air, in treetops, in burrows or under water. The different locations will introduce different noise attenuation rates due to different distance, absorption, screening and excess attenuation effects with the result that the noise exposure or frequency content may alter from one receiver location to another for the same noise source. Burrows and dens should protect occupants from noise but a further possibility is that amplification of some frequencies may arise within burrows or holes, perhaps as a consequence of resonation effects or standing waves within tunnel lengths.

Simultaneous measurements above and inside small rodent burrows of Merriam's Kangaroo Rat (*Dipodomys merriami*) and the Kit Fox (*Vulpes macrotis*) have been undertaken during low-level jet overflights by F-15 Eagle, F-16 Falcon and A-10 Warthog attack aircraft[340]. Noise levels from the F-15 can exceed 120 dB directly under the flightpath and F-16 can exceed 110 dB. With the burrow microphone placed approximately 70 cm from the mouth of the burrow, the mean noise attenuation from outside to inside the burrow during 6 overflights (2 of which included 20mm cannon fire) was 2.4 dB, which is not significant in the context of environmental noise exposures.

Due to the relatively small amount of attenuation within the burrow, further analysis of the frequency-dependent attenuation was undertaken. The underground microphone was 42 cm inside the burrow, with 33-45 cm of soil above, and with an elliptical hole measuring 10 by 8 cm. For a F-16 flying at 200-400 m AGL and a slant distance from the burrow of 280-450 m, noise levels inside the burrow were very similar to the external levels up to 1300 Hz but above this frequency noise levels were increasingly attenuated. Similar recordings made in a kit fox burrow but with the microphone further into the burrow (approximately 2.3m from the entrance) produced much more pronounced levels of attenuation than in the shorter and shallower burrows of the kangaroo rat. The fox den attenuated noise down to 500 Hz, with 20 to 40 dB attenuation between 1000 and 4000 Hz.

The low frequency sensitivity of the kangaroo rat and other desert rodents has already been identified. Their optimum hearing range is 125 to 1500 Hz, which is mostly below the threshold of 1300 Hz identified above at which some degree of attenuation in shallow burrows does occur. Therefore, it would appear that for kangaroo rats and similar rodents, even when sheltering inside their burrows there would be little protection against external sources of low frequency noise such as ORVs or low flying jet aircraft. If the rodents dug longer and deeper burrows, then the indication is that external noise would be attenuated to a greater extent as for the kit fox. However, the kangaroo rat is dependent on its low frequency hearing ability to hear the foot drumming of its competitive neighbours or the approach of predator snakes, and to live at a deeper position below ground would in this respect be disadvantageous. Therefore, where low frequency noise is concerned, the kangaroo rat and similar rodents are doubly disadvantaged, firstly due to their physical and physiological adaptations with respect to their ears, and secondly their behavioural/lifestyle adaptations.

Figure 4.1: Simultaneous noise levels recorded outside and inside mammalian burrows during overflights by F-16 jet aircraft[340]



F-16 overflight of small rodent burrow	F-16 overflight of kit fox burrow

In contrast, the kit fox has relatively poor hearing below 500 Hz and their burrows provide significant attenuation to external noise above 500 Hz, therefore, when inside their burrows the animals are well protected from external noise by as much as 20-40 dB as shown by the researchers external and internal noise levels in Figure 4.1. Apparently, the deeper burrow used for the comparative measurements was fairly straight (a requirement for installing the microphone), whereas most kit fox burrows bend several times as they descend. There is, therefore, a strong probability that in most cases the noise level attenuation would be greater still due to the presence of bends.

However, guidance is needed on how the above information can be applied to environmental assessments. Unfortunately, the findings of noise levels within burrows show once again that it is not a simple case of applying a common attenuation factor to all situations. The absolute noise level and hence noise exposure of an animal inside the burrow will be dependent on the type of animal, once again its hearing sensitivity, the length of the burrow and also its depth below ground level. In addition, the alignment of its entrance relative to the noise source is also likely to have some bearing on the actual noise level within the burrow.

From the information presented here, it would appear that burrows where the occupants would be less than 1m from the surface will not provide a significant amount of noise attenuation (i.e. <3 dB) compared to the normal variations one can expect at ground level. Therefore, for assessment purposes it would be appropriate not to include any attenuation for animals within short or shallow burrows. Where it is known that animals will be resident within deeper/longer burrows during a noise exposure, i.e. 2m or more from the surface, then it would be reasonable to apply an attenuation, which could amount to 20 dB or more subject to site specific circumstances such as those discussed in the preceding paragraph. The following study further demonstrates that when an animal is in a den that is more fully closed off from the atmosphere, the attenuation may increase to up to approximately 40 dB. However, wherever possible the assessment should take account of the frequency composition of the noise, the sensitive hearing frequencies of the animal, and the relative attenuations over the frequency ranges shown in Figure 4.1.

Measurements[341] undertaken inside and outside an artificial polar bear den during the take-off of a helicopter at 3m from the den showed a noise reduction of 38 dB from 115 dBLin outside the den to 77 dBLin inside the den through 1m of dry snow. At distances of 300m from seismic activity, noise and vibration levels were undetectable, and at 100m the activity resulted in den noise levels of 40 dBLin.

This section has considered specific habitat or topographical features that may affect the noise level at the animal position. An unusual consideration is the types of sounds that may be audible to migrating birds. In this respect, historical data is available from balloonists[342] and has produced information relating to the likelihood of noises being audible at different altitudes as shown in Table 4.3.

Table 4.3: Cases of different sounds heard by balloonists at three altitude ranges[342]

Type of sound	No. of cases when sounds audible			
	Altitude at which sounds heard			Total no. of cases
	Below 1,000m	1,000 to 2,000m	Above 2,000m	
City sounds	10	5	1	16
Country sounds	9	7	4	20
Water sounds	4	10	5	19
Human voices	26	12	1	39
Musical instruments	7	7	3	17
Guns	6	7	9	22
Trains	4	5	11	20
Ground echoes of sounds from balloons	6	5	0	11
Sounds heard at night	18	11	1	30
Sounds heard whilst inside clouds	28	27	10	65

Table 4.3 shows that ambient noises from normal human activities as well as from natural sources, are audible to humans at heights of up to and beyond 2,000m above

ground level, and, therefore, are likely to be equally audible to flying birds. Apart from ground echoes of sounds generated from the balloonists, all sounds were audible at some time above 2,000m, although those sources that were heard more often above 2,000m were noise from gunfire and trains. It is possible that after repetitive migrations some birds may use auditory signals from the ground as part of their navigation process in addition to information from the stars and electromagnetic radiation. If this is the case, then the environmental assessment process would need to consider not only the horizontal but also the vertical propagation of noise from the new noise source if the site lay under a migratory flightpath.

The highest of all reports (7,150m) was initially described as the sound of thunder below the balloon, but which was subsequently identified to be the sound of artillery practice. The sounds of cars and train whistles have been heard at altitudes up to 6,650m. Night-time sounds would be of most relevance to birds because most migration takes place at night. In this respect, barking dogs have been heard up to 2,145m, croaking frogs at 900m and the call of the mole cricket at 750m. Running water in rivers and streams has been described as producing sound equivalent to that of a waterfall even at heights of 1,000m. If sounds generated at ground level might have some bearing on bird migration, then it is the continuous noises rather than intermittent and irregular noises such as trains and gunfire noise that would be present during the migration period and thus have the potential for an effect as yet unknown.

4.5 Background Noise Level

Background noise levels will be important because the higher these are, the smaller will be the difference between the intruding noise and the background, and, possibly, lesser impacts will arise. There is evidence that the difference between the intruding noise and the background noise has some significant bearing on human annoyance reactions, as demonstrated by the procedures in BS4142[343] used to determine the likelihood of complaint due to industrial noise emissions. However, few of the animal studies equate change relative to the background noise level; most tend to relate the response to an absolute noise level (see Chapters 2 and 5). Therefore, further research is necessary before determining the extent to which the difference between the intruding noise and the background noise level will influence an assessment process for animals. Nevertheless, some regard should be given to the background noise level during an assessment of noise impacts.

In the UK, rural areas and national parks remote from civilisation are likely to have the lowest background noise levels. In other countries, deserts, scrubland and prairies etc. will equally have low background noise levels. Intruding noises within these areas are likely to have a greater potential for impact because they will experience less masking from other ambient noises. Factors influencing the background noise level are discussed in other sections of this chapter, e.g. section dealing with meteorology, and natural contributors such as wind speed and direction and the type of habitat and amount of vegetation/foliage through which the wind is blowing strongly influence the background noise level.

In the absence of background noise measurements it would be helpful to have procedures for estimating background noise levels for a given situation. A method for determining background noise levels due to wind speed has been derived in the Netherlands using the L_{A95} index[344], and the equations are presented below for a situation representing open agricultural grassland in summer. (Values of annual average wind speeds in the UK are discussed later in Section 4.9 together with consideration of the effect of wind speed on background noise level.) Different relationships are likely to apply to different habitats in different seasons. In the UK we use the L_{A90} to denote background noise levels, however, for general assessment purposes there is unlikely to be significant variation between the two indices.

$$L_{95} = 37.9 \log(v) + 42.5 \quad \text{dB}$$

$$L_{A95} = 22.6 \log(v) + 22.7 \quad \text{dB} \qquad (4.2)$$

Where v = wind speed, m/s

In some instances, the level of background noise may influence the sounds emitted by animals, for example, the structure of the blackbird song is modulated according to the level of background noise[345]. Characteristically, the song's 'twitter' is high in frequency and low in amplitude, and, therefore, attenuates rapidly. However, in locations where there are high levels of man made noise the twitter component is shorter and plays a lesser role within the song. Therefore, prior to the introduction of a new noise, the existing background noise level can affect the manner in which an animal communicates with other members of the species group. The raising of the background noise level due to the introduction of additional noise, may cause communication to be further altered or it could have a masking effect and hence reduce communication distances, either of which could affect the distribution of local populations.

However, when considering the potential for changes to the background noise level to impact upon animals, regard needs to be paid to the fact that under normal circumstances there can, in any event, be significant variations to L_{A90} levels measured long-term. For example, the typical spread of L_{A90} noise levels shown in Figure 4.2 of Section 4.9 is 15 dB or more at constant wind speeds. If man made noise changes fall within the normal range of seasonal variations, the impacts upon animals may be less significant but matters such as the overall duration and coincidence with sensitive behaviour will still be important.

4.6 Source Characteristics

Some noise sources may comprise unusual acoustic characteristics that may have a stronger influence on the manner in which animals respond. A good example of this is helicopter noise, which comprises not only a complex mix of noise frequencies within the emitted signal, but the radiated sound field with distance from the helicopter is also complex. In addition, small changes in flight condition and operation, e.g. the descent rate, can produce major changes to emitted noise levels. The latter fact means that if the operational circumstances are not particularly well defined at the environmental assessment stage, the noise exposure and hence the animal response may be underestimated.

The highest levels of helicopter noise tend to be associated with high speed impulsive noise, which largely arises from the effects of blade thickness. However, at lower flying speeds the highest noise levels tend to arise from Blade-Vortex Interaction (BVI)[346]. The consequence of BVI is that the noise radiated from a helicopter will possess a number of highly localised maxima where the sound level will be significantly higher than would otherwise be expected from sound decaying under normal inverse square law circumstances. The maximum BVI noise occurs under partial power descent when the main blades run close to or interact with their shed wake.

The studies of animal response to aircraft noise clearly demonstrate that helicopter noise tends to cause much stronger or more responses than for fixed wing aircraft. This effect is similar to that for humans in that noise from helicopters often causes more annoyance than equivalent fixed wing aircraft noise of the same nominal level. It has been postulated that some animals may use the rate of change of noise to establish to what degree a noise source may pose a threat and whether the animal should flee from the threat. The variations within the helicopter noise signature are likely to make it difficult for such animal's to use this approach, which may explain the greater response due to helicopters compared to fixed wing aircraft. Equally, however, localised regions of high noise level due to the BVI effect are also likely to make it difficult for an animal to obtain the same sort of information that it might from other mobile sources. A moving animal may move rapidly into and out of the BVI noise peaks, or conversely the moving helicopter may cause BVI noise peaks to pass over a stationary animal. Sudden changes in noise level of this nature may not enable the animal to accurately determine the proximity and location of the source. As a result, it is more likely to feel insecure and apprehensive, and hence more likely to show a stronger or more frequent response compared to other noise sources.

The complexity of helicopter noise and features such as the BVI effect illustrate the importance of accurately identifying the various noise characteristics that might comprise the noise source under investigation. Therefore, in order for an environmental assessment to be able to conclude the degree of impact on animal communities, it will be necessary to establish that specialised acoustic features are not present at any stage during the noise source's operation. If they are, then an appropriate level of assessment will be required to ensure that the possible effects on local animal populations are not ignored. The literature review indicates that, in addition to helicopters, sonic booms, rocket propulsion systems and off-road vehicle noise are the types of noise sources that are either more likely to cause adverse responses in animals or more likely to involve different sound propagation effects. Further studies need to be undertaken to establish whether other sources such as hovercraft have similar characteristics.

4.7 Noise Monitoring

It has already been demonstrated by way of the hearing sensitivities of different animal species that the A-weighted noise indices used for noise impact assessments for human populations are unlikely to reflect either the received noise level or be directly related to behavioural responses of all animal species. Therefore, when undertaking ambient noise surveys intended to be representative of the noise levels within animal habitats, care needs to be taken to use the weighting most appropriate for the animals under study. If necessary, measurements should be undertaken using both linear and any other selected weighting, as well as octave band analysis.

A further problem is that the monitoring equipment itself may not reflect the same frequency characteristics as the animal under consideration. For example, high frequency sensitive microphones and insect ears differ substantially with respect to their absolute sensitivity, directionality, and temporal characteristics with the result that noise levels recorded through the microphone transducer may be different from what the insect would actually hear, even when monitoring at the same position in the habitat. Similar comments will apply to those animals having special hearing characteristics.

Being able to place the microphone at a position representative of the animal in the habitat may also be an important issue for some animal studies. In many instances where small mammals are concerned, the size of the noise measurement device may be greater than the animal, and its introduction within the exposure zone may cause changes to the noise climate due to scattering and reflections. However, the change is unlikely to be greater than the changes that will arise naturally, often over short distances, due to air currents, eddies, reflections and screening effects etc. as an animal moves within its territory.

Noise surveys for most EA studies are probably undertaken with the microphone in a free-field position at a height of 1.2 to 1.5m above ground level. This may be reasonable for most situations where only general consideration is being given to noise effects on animals but when the assessment studies are to relate to specific animals, the measurement and assessment points should equate to the normal location of the animals relative to ground level. This may not be practicable or possible in the case of birds roosting at tops of trees or birds in flight. The firing of MLRS at Otterburn was observed to cause birds to take flight into the path of the rocket, which may cause them to experience higher noise levels than if they had stayed on the ground. The measurement of noise levels in such circumstances is not an easy proposition, therefore, in the absence of published data an option would be to calculate back from noise levels measured at a reference distance on the ground.

4.8 Behavioural Characteristics

This topic is one of the most important in any EA in that it is essential that the behavioural repertoire of the species under consideration must be known in sufficient detail in order to establish whether exposure to noise will have adverse effects on individuals or on local population numbers. It has been demonstrated that animal responses can vary significantly between species, and also that a specific response that may be perceived as harmful in one species may be inert or even beneficial in another.

As an example, species richness of birds has been shown to significantly decrease as ambient noise increased[347], though the study in question did not measure noise levels but placed them within the subjective categories of low, medium and high. If one reads this at face value one might assume that birds as a whole decrease in number as the ambient noise level increases, however, only some birds are affected in this way. Although sensitive species of birds may avoid noisy environments or be less able to survive within them, other cosmopolitan species may be more tolerant and able to dominate the sensitive ones, thereby causing a change in the species richness. What is important for an environmental assessment is to be able to identify those species that are sensitive or hardy so that species specific responses can be properly established.

Man made noises may cause animals to alter their normal behaviour and the long term significance of this will require consideration with respect to the species viability. An example of this is the recorded 29% extension to the song of the male humpback whale. It is possible that the longer songs serve to counteract the noise of the sonar but it is too early to say whether the change could have any long term implications such as on demographic patterns.

Changes to the male humpback song have also been observed in the absence of a low frequency signal as evidenced by the complete shift from an old to a new song in populations of humpback whales off Australia between 1995 and 1998. As mentioned in Appendix IV, it seems too coincidental to expect an evolutionary trend such as the song change to occur just at the time of the study, especially since such changes would normally be a slow process over many years to enable natural selection to work. It seems more probable that the change was initiated by other outside factors, and low-frequency transmissions within the ocean would be a possibility.

Vocal signals are often used to maintain cohesion among members of a family group or local population, for example in the case of flocks of waterfowl. Alarm calls given by parent birds in response to danger are also often species-specific and elicit an instant and in-bred response from young birds, which clearly help in their ability to survive. There may, therefore, be a risk of low levels of noise interfering with such important communication signals, especially if the intruding noise is continuous rather than intermittent. Particularly susceptible periods may arise during each year such as when migratory birds gather in the spring and fall at staging and stopover points, where they may remain for several weeks feeding in preparation for breeding or migration. Smaller moulting groups will also form during mid to late summer.

It is also important to understand physiological responses following a startle response. For example, running/flight responses will often involve energy expenditure. In some cases, the return of some animals to water, e.g. seals, is likely to alter their thermo-regulatory balance, which may in turn affect their energy expenditure. However, some diving animals, e.g. birds such as loons and ducks, initiate specific physiological responses when they dive, which involve predictable changes in heart rate, cardiac output and blood circulation that are designed to enable them to minimise their metabolic rate and hence stay under water longer[348,349]. Such procedures will at the same time minimise their energy expenditure. Therefore, for such species, rather than the startle reaction causing further adverse reactions due to energy expenditure, the end result – diving – is actually beneficial since the physiological responses rapidly return the animal to an unstressed state with a low metabolic rate and relatively normal levels of energy expenditure. These differing responses show that the importance of the noise response cannot always be classified using the observable physical response since 'invisible' physiological responses may be greater or over-ride the first reaction.

Interruptions to feeding in the spring is likely to be more important for larger species such as geese that rely heavily on stored energy reserves for egg production and incubation than for smaller species such as ducks that feed throughout the nesting period. Accumulation of sufficient fat reserves in the fall is critical for all migrating waterfowl. Geese often compensate for daytime disturbance by foraging at night but this is likely to be less efficient and may not necessarily redress the energy imbalance caused by the daytime disturbance.

Common loons (in the UK, loons are known as divers, and the common loon is known as the Great Northern Diver (*Gavia immer*)) moult in the early spring whereas red-throated loons (red-throated divers (*Gavia stellata*)) moult in the fall. This shows the importance of being aware of different behavioural traits between similar species. Shedding and regrowth of flight feathers is accompanied by changes in the relative mass of muscles between the legs and wings[99], which is likely to place higher energy demands on the birds.

The effect of disturbance on social structure is also important. Flocks of Canada geese for example, often comprise numbers of subgroups based on family groupings that help them to remain stable and feed and roost successfully. Breaking up these groups can lead to increased aggression and reduced access to food. The structure also has advantages for juveniles in terms of learning and protection. Flocks flushed by noise may not always return to the same large groupings, which can disrupt the social structure, reduce the benefits outlined above and increase the mortality rate due to predation.

Canada geese normally cover their eggs with down and vegetation before leaving the nest in order to keep eggs covered and warm in their absence[350]. Noise sources that cause the geese to depart suddenly will leave eggs exposed to either predation or heat loss.

Development of bird song occurs over the first few days after a chick hatches, and a chick isolated from normal song stimuli is likely to develop simplified abnormal songs[351]. Reduced social contact during these development stages can lead to under-developed auditory perceptual abilities[352], i.e. deficits in relation to the discrimination of frequency range, frequency ratio and song notes, and an inability to discriminate between the normal range of species vocalisations[353], although the latter study concludes that discrimination of distance cues and hence distance perception is likely to be an innate skill rather than one learned through experience and dependent on development of vocalisation skills. Nevertheless, it is evident that sustained levels of noise exposure during the early development stages of songbirds could have some significant adverse effects on their ability to not only vocalise but to discriminate between auditory cues that would otherwise be recognisable.

Vocalisations are also important in enabling animals to find mates and/or young in large colonies. In the case of birds this has been referred to as a 'two-voice' phenomenon[354], which refers to birds' ability to produce two distinct sounds independently but simultaneously. This ability is particularly important for birds such as emperor penguins that need to identify partners, parents or chicks within groups comprising many thousands of animals. The 'two-voice' calls within the emperor penguin are more complex than other species and it is postulated that identification and location takes place using counter-calling and approach techniques[355]. In a similar manner, it is important for fur seal mothers to be able to find their pups within large colonies[356] after leaving them for periods of up to 2 weeks whilst they forage for food. Both mothers and pups have been found able to recognise each other's voices even after periods of at least four years[357]. Evidence of vocal recognition between individuals is rare within the animal kingdom, nevertheless, it is likely to play an important part in social behaviour of colonial species in particular, and any extraneous ambient noise that can interrupt/mask the recognition processes, which are likely to be most active during the early days of newborn pups etc., could have adverse implications for a pup's development. However, ambient noise levels within animal colonies are likely to be relatively high due to the regular calling between mates, parents and young, and the processes involved in vocal recognition between individuals are likely to occur when the individuals are in close proximity. For these reasons, it seems unlikely that typical extraneous environmental noise would be loud enough to interfere between close-quarters communications that occur within a naturally noisy environment.

Crows, ravens and jays are often attracted to loud and unusual noises and often investigate sources of disturbance[358,359]. This is consistent with the early reference to crows etc feeding alongside motorways. The motorway verge can provide a useful source of food for these and other species of birds, however, their presence shows their tolerance of noisy conditions. It is possible, therefore, that flocks of these birds raised by noise sources, e.g. sonic booms, may not be an indicator of disturbance but possible attraction to or investigation of an event.

Nest abandonment is more likely early on in the breeding season when less effort has been invested in nest building. Nest abandonment in grouse decreases as breeding season progresses[360].

Some birds have low energy reserves, e.g. grouse and ptarmigan, and rely largely on the insulative qualities of their plumage to survive the winter. The ruffled grouse includes behavioural strategies such as burrowing into the snow during storms[361]. Excessive disturbance at such times could cause unfavourable changes to their energy balance.

4.9 Meteorological Factors

The background noise at an animal's position (see Section 4.5) may be relevant in terms of whether the intruding noise is higher or lower and thereby likely to be masked. Wind is often a major factor in determining background noise levels, especially when vegetation is in leaf. When vegetation rustles in the wind a broadband noise is produced, which can have a noise level of approximately 35 dB(A) for a 1 m/s wind speed, or up to 60-70 dB(A) at 8 m/s[362]. Vegetation/wind noise can have a masking effect on some animal calls, and this will amount to a natural and regular occurrence that an animal's behavioural characteristics have to compensate for. As a consequence, if an intruding noise is no noisier than the natural noise, the question must arise as to whether it can then have an adverse impact on the animal. If it is no more regular than the natural noise then the answer must be no. If it is constant then persistent masking of animal calls may be possible, which would be of greater concern. However, it must also be recognised that wind direction as well as wind speed is important in determining absolute background noise levels, and changing wind patterns, as will be discussed later, will prevent intruding noises from being constant.

Unpublished noise measurements recorded by Hyder Consulting Limited during a baseline noise survey at Port Talbot, South Wales, have been analysed with a view to correlating background L_{A90} noise levels with wind speeds. The monitoring equipment comprised a Bruel & Kjaer 2260 Investigator sound level meter with outdoor noise measurement kit comprising microphone windshield and weatherproof enclosure, and a B&K 4231 sound level calibrator. Noise measurements were made using the 'Fast' time response and A-weighting frequency response. The microphone was located on a 4m high Clarke mast that was extended to an overall height of 8m above ground level, and simultaneous measurements of wind speed were also recorded at the same monitoring position using a 'Second Wind's NOMAD' anemometer at a height of 10m to log wind speed every 10-minutes. The location was open and exposed to the sea winds, without any local development in the vicinity, and there were no other significant sources of noise. Monitoring commenced on 25 October 2002 when weather conditions for the region were normal, and continued for a further 6 days until 31 October during which time storm force winds blew in from the Atlantic and hit the southwest of the UK.

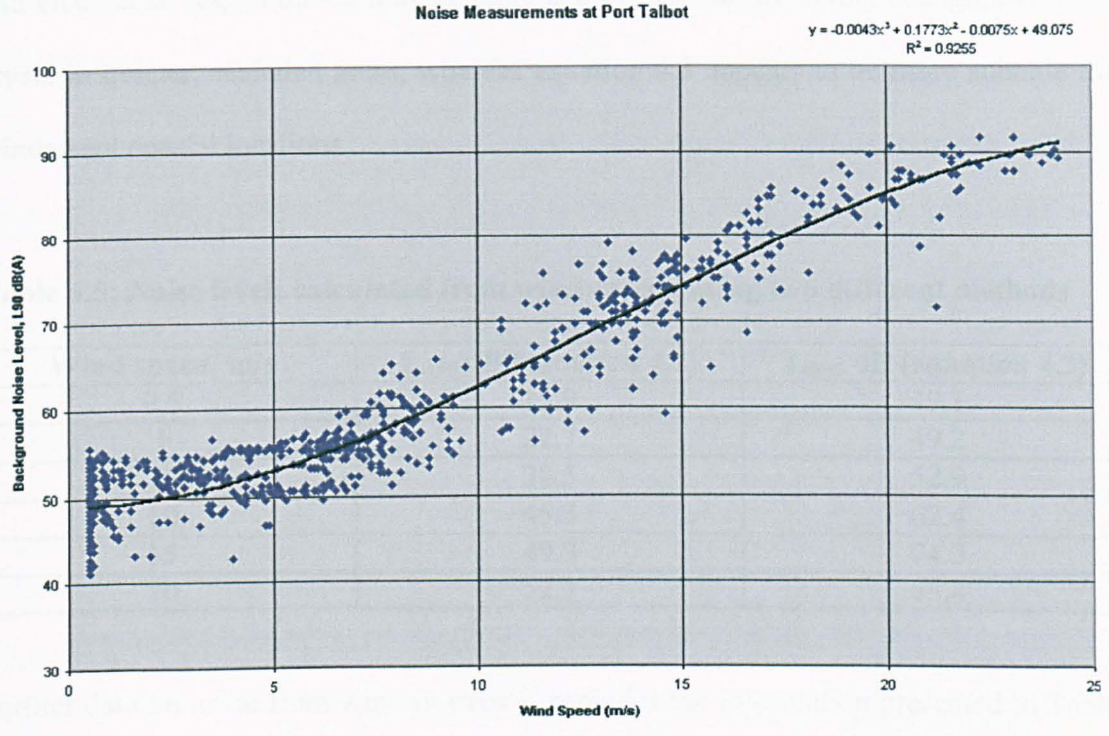
Wind speeds during the survey ranged from 0.5 m/s to 24.2 m/s (i.e. 55 mph maximum), and for comparison purposes the Beaufort scale has been converted to metric wind speeds in Table 4.4. This shows that the highest recorded wind speeds equated to force 9 to 10 winds, or strong gale to storm conditions.

Table 4.4: Conversion of Beaufort scale to other measures of wind speed

Force	Description	Wind speed	
		knots	m/s
0	Calm	0	0
1	Light air	1-3	0.5-1.5
2	Light breeze	4-6	2.0-3.1
3	Gentle breeze	7-10	3.6-5.1
4	Moderate breeze	11-16	5.6-8.2
5	Fresh breeze	17-21	8.7-10.7
6	Strong breeze	22-27	11.2-13.8
7	Near gale	28-33	14.3-16.8
8	Gale	34-40	17.3-20.4
9	Strong gale	41-47	20.9-24.0
10	Storm	48-55	24.5-28.1
11	Violent storm	56-63	28.6-32.1
12+	Hurricane	64+	≥32.6

The L_{A90} and wind speed measurements (m/s) are plotted in Figure 4.2 together with the trendline for the data. At the lowest wind speed (0.5 m/s) it can be seen that the L_{A90} for the locality ranged from 41 to 56 dB during the survey period. The trendline shows the rate at which the background noise level increased with increasing wind speeds; at 5 m/s the L_{A90} was typically 53 dB, at 10 m/s it was 62 dB, at 15 m/s it was 74 dB and at 20 m/s it was typically 85 dB. This approximately equates to a 10 dB increase, i.e. a doubling of loudness using the subjective scale applicable to the human ear, for each 5 m/s increase in wind speed.

Figure 4.2: Measured effect of wind speed on background noise level at a coastal location during storm force winds.



The trendline equation for the data in Figure 4.2 is as follows:

$$L_{A90} = -0.0043v^3 + 0.1773v^2 - 0.0075v + 49.075 \quad dB \qquad (4.3)$$

Where v = wind speed, m/s

The above equation, and the Netherlands equation applicable to open agricultural grassland in summer (see section 4.5 - Background Noise Level, equation 4.2), have been used to calculate comparative noise levels for different wind speeds and the results are presented in Table 4.5. Although some differences are to be expected between the L_{A95} and L_{A90} values it is clear that equation 4.2 results in substantially lower noise levels than equation 4.3. At low speeds (0.5 m/s), noise levels using equation 4.2 are approximately 33 dB(A) lower; the difference decreases to 14 dB(A) as wind speeds increase to 5 m/s, and then increases again to 33 dB(A) at 20 m/s. At all times, equation 4.3 results in higher noise levels, which illustrates the need to use information and methods that are specific to the location being assessed, i.e. data applicable to open agricultural grassland in summer is not suitable for open coastline situations in autumn and vice versa. Equation 4.2 may be more appropriate for predicting background noise levels in quieter, secluded areas, whereas equation 4.3 appears to be more suitable for windswept coastal locations.

Table 4.5: Noise levels calculated from wind speeds using two different methods

Wind speed, m/s	L_{A95} dB (equation 4.2)	L_{A90} dB (equation 4.3)
0.5	15.9	49.1
1	22.7	49.2
5	38.5	52.9
10	45.3	62.4
15	49.3	74.3
20	52.1	85.4

Further data on noise from wind in trees[363] provides the information presented in Table 4.6. The percentage time that wind speeds are present during the year has been estimated from Met. Office data for the central UK. These values will vary from site to site. The predominant annual average wind speeds tend to be in the range of 7-10 knots (3.5-5 m/s), which are likely to produce ambient noise levels when blowing through trees of up to 50 dB(A).

Table 4.6: Published data relating to noise levels due to winds blowing through trees in leaf[363]

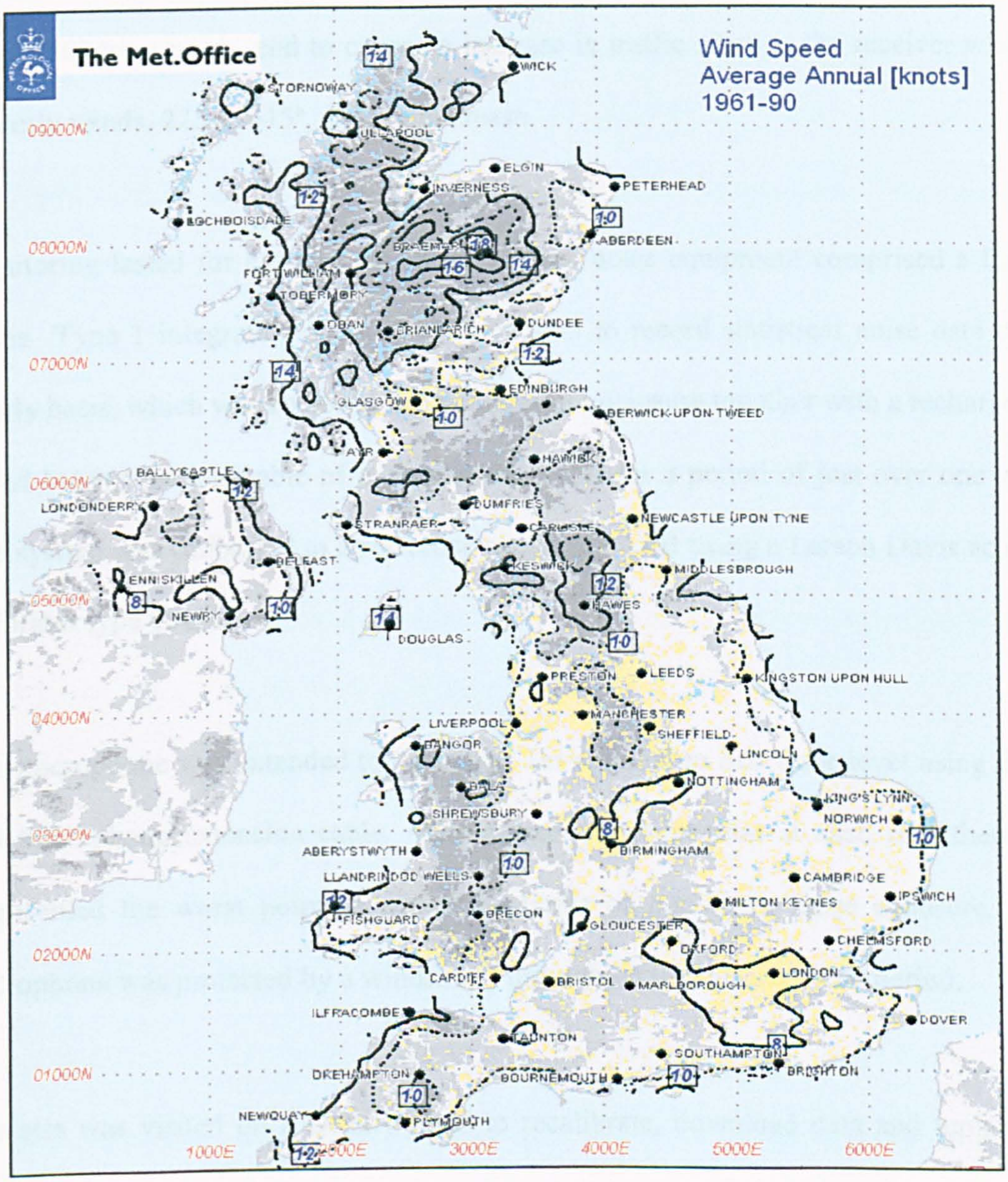
Beaufort Scale	Description	Wind speed			Noise level dB(A)
		Knots	m/s	% occurring	
0	Calm	0	<0.5	10	-
1	Light air	1-3	0.5-1.5	20	39-43
2	Light breeze	4-6	2-3	19.7	43-46
3	Gentle breeze	7-10	3.5-5	24.2	47-50
4	Moderate breeze	11-16	5.5-8	18.6	50-52
5	Fresh breeze	17-21	8.5-11	4.3	52-55
6	Strong breeze	22-27	11.5-14	0.8	55-58

The Beaufort scale extends beyond the category of strong breeze to include gale and storm conditions. Clearly the wind speeds and hence noise levels would be much higher during these conditions but of course they represent a much smaller percentage of the year. It is true that animals would have to contend with the higher noise levels during these extreme conditions but there is little or no information on the short and long term noise effects of such events. In any event, it is more likely that other factors such as the high wind speeds themselves or associated torrential rain conditions would be more damaging for wildlife.

Annual average wind speeds for the UK are compiled by the Met. Office as illustrated in Figure 4.3. Using this information and the data in Table 4.6 it becomes possible to estimate typical ambient noise levels in woodland sites for different proportions of the year, which might be useful when comparing noise levels likely to be generated by a new noise source.

The estimated noise level would exclude other ambient noises, such as from existing wildlife, e.g. birdsong, which can often be a dominant source of noise in rural areas. It should also be noted that Met. Office data is typically gathered at 10m above ground level at its weather stations. Wind speeds closer to ground often reduce due to friction effects but equally they can be increased due to turbulence effects around structures. Therefore, application of Met. Office data to conditions at the animal position once again can only be done with caution.

Figure 4.3: Annual average UK wind speeds (knots) measured by the Met. Office, 1961-1990



The wind direction tends to be a dominant factor in determining the absolute noise level at a receiver location, with highest levels being recorded downwind of a noise source and lowest values upwind. In order to quantify the effects of meteorological conditions on environmental noise levels I undertook long term monitoring of both noise and weather conditions at a site affected by motorway noise, which is a relatively constant noise source that is often strongly affected by weather conditions. The motorway followed a north-south alignment and was screened from receivers to the west by a 3m high noise barrier. Noise levels were recorded at a receiver located west-northwest of the motorway at a distance of approximately 220m. Southeasterly winds, e.g. between 80 to 180° from north tend to cause an increase in traffic noise at the receiver whereas westerly winds, 225 to 315°, cause a decrease.

Monitoring lasted for a period of 28 days. The noise equipment comprised a Larson Davis Type 1 integrating sound level meter set to record statistical noise data on an hourly basis, which was enclosed in a waterproof enclosure together with a rechargeable Nicad battery pack capable of powering the meter for a period of just over one week. The system was calibrated to a reference signal of 94 dB using a Larson Davis acoustic calibrator type CA200.

The microphone was extended to a position 1m external to first floor level using a pole and microphone extension cable. The measurement location at each site, therefore, represented the worst point of impact in terms of maximum noise exposure. The microphone was protected by a windshield throughout the measurement period.

The site was visited on a weekly basis to recalibrate, download data and replace the battery pack. The equipment repeatedly reproduced a calibration level of 94 dB throughout the survey period demonstrating that the microphone system remained stable and produced accurate data.

Simultaneous measurements of local weather conditions were also undertaken during the survey period. The weather station comprised an ELE International's type MM900, which incorporates a data logger that can be configured to monitor and record data over different time periods. The station was fitted with sensors for wind direction, wind speed, barometric pressure, temperature and relative humidity, and data from each sensor was sampled every 5 minutes. These measurements were then stored on the logger as 1-hour averages. With respect to traffic noise measurements, CRTN stipulates that the average wind speed should be not more than 2 m/s in the direction from the road to the reception point, and that the speed in any direction should not exceed 10 m/s. The wind speed data (see Figure 4.4) confirms that these conditions were met.

For each full day of monitoring the $L_{A10\ (18\ hour)}$ noise level was derived by averaging the 18 hourly L_{A10} noise levels between 0600 and 24 hours, and this information is plotted as the green line on each of the meteorological graphs presented in Figure 4.4. The 1-hour average values for each meteorological sensor have also been plotted against time and are presented as the blue traces in Figure 4.4.

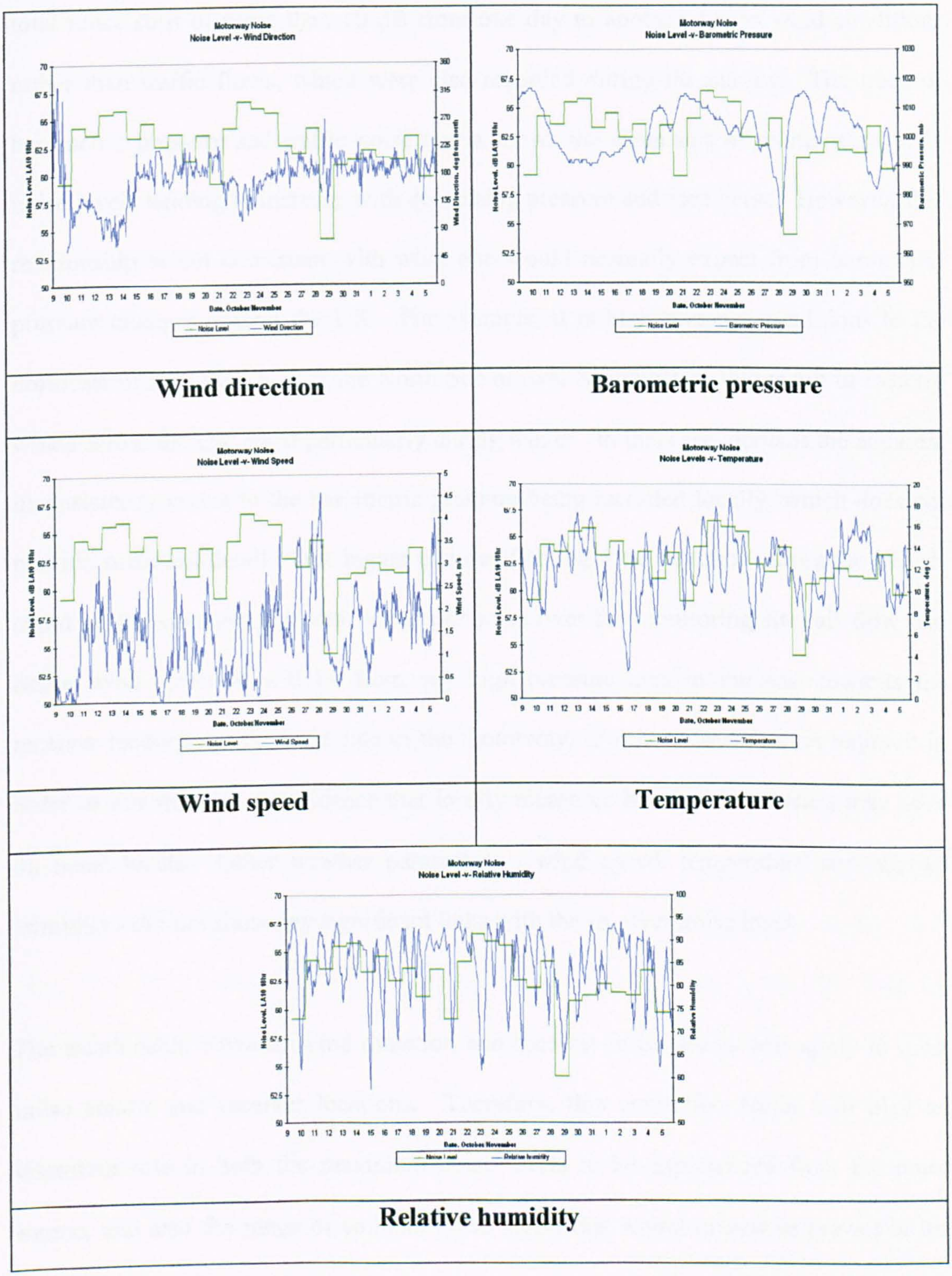
The first graph displays the wind direction data and shows that for the majority of the survey period winds were regularly blowing from between 180 to 225° (measured from north which is represented on the graphs by 0 or 360°). This sector is equivalent to winds blowing from the south-southwest (SSW), which is consistent with prevailing winds in the UK being approximately south-westerly. Under these conditions, motorway noise is not refracted towards receivers located to the west of the motorway. However, soon after commencing the survey, between 10 to 15 October, and again between 21 and 25 October, the graph demonstrates that winds were blowing from between 90 to 180° from north, i.e. from the south-east quadrant. Winds from this direction cause refraction of noise from the motorway towards the monitoring point.

The second graph displays barometric pressure. The typical range during the survey period was 990 to 1015 millibars (mb) though a particular low occurred briefly on 28 October, dropping to 970 mb. The data appears to show a clear relationship with noise levels in that for most days, when the barometric pressure rises the noise level falls and vice versa. In this way, the period of easterly winds reported above between 10 to 15 October, which resulted in higher noise levels at the monitoring location, coincided with a period of lower pressure between 12 to 18 October. However, easterly winds are normally associated with high pressure conditions as will be discussed later.

The third graph displays wind speed. For the majority of the time, wind speeds were below 2 m/s and, therefore, satisfied the CRTN monitoring requirement that the average wind speed should be not more than 2 m/s in the direction from the road to the reception point. Peaks of between 2 to 4.5 m/s were also recorded, however, the frequency of these would not have significantly altered the overall average wind speed each day. Wind speeds constantly higher than 2 m/s were recorded on 28 October (cf low barometric pressure on this date), however, since the noise monitoring site did not exhibit abnormally high noise levels on this date, the data has not been excluded from the assessment. For reference purposes, 1m/s is equivalent to almost 2 knots, therefore, the highest recorded speed of 4.5 m/s is equivalent to about 9 knots.

The fourth graph displays temperature. For the majority of the time, ambient temperatures ranged between 7.5°C at night to 17.5°C during the day. Finally, the fifth graph displays % relative humidity, which ranged from 65 to 95% over the survey period.

Figure 4.4: Comparison of $L_{A10\ 18\text{-hour}}$ traffic noise levels measured at 220m from a motorway with meteorological conditions measured at the same position



With southwesterly winds blowing from the motorway (e.g. 10-15 and 22-25 October), noise levels can be seen to rise by up to 5 dB(A) compared to the typical noise level at other times. During calm conditions (e.g. 29 October) noise levels fell by more than 5 dB(A). As a consequence, receivers adjacent to this traffic noise source experienced a total noise shift of more than 10 dB from one day to another due to wind conditions rather than traffic flows, which were also recorded during the survey. The trace of barometric pressure and traffic noise levels shows the same sort of relationship, with noise levels tending to increase with decreasing pressure and vice versa. However, this relationship is not consistent with what one would normally expect from barometric pressure changes around the UK. For example, it is high pressure conditions to the northeast of the UK, i.e. over the North Sea or over Scandinavia, that result in easterly winds across the UK, most particularly during winter. In this case, perhaps the apparent inconsistency is due to the barometric pressure being recorded locally, which does not provide sufficient detail of the bigger picture affecting wind direction across the UK. It could be the situation that with lower pressures over the monitoring site, air flow and hence wind direction will be from any high pressure area in the east towards the receiver locations to the west side of the motorway. Further assessment is required in order to establish the significance that locally measured barometric pressure may have on noise levels. Other weather parameters - wind speed, temperature and relative humidity - did not show any significant links with the receiver noise level.

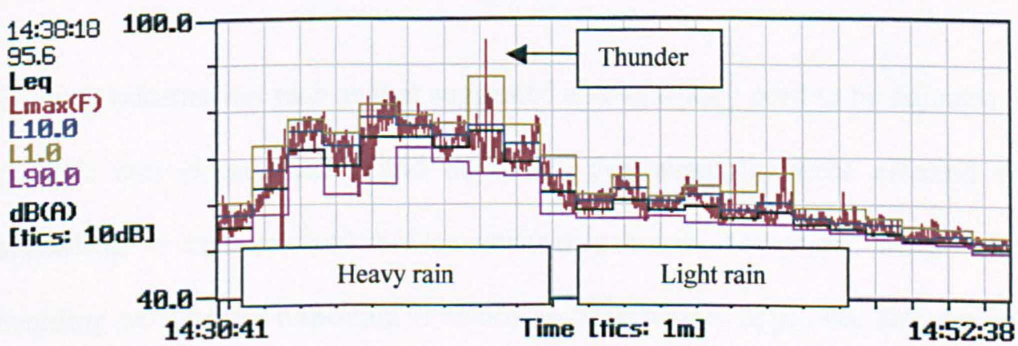
The relationship between wind direction and receiver noise levels will apply to most noise source and receiver locations. Therefore, this correction factor will play an important role in both the maximum noise levels to be experienced from the noise source, and also the range of ambient noise levels that would otherwise prevail in the absence of the source. An EA will need to take account of the possible maximum noise level from the intruding noise source and compare this to the background and typical ambient levels at the animal's territory. However, wind direction can have different effects on ambient sources and the intruding noise source. For example, noise from a normally prevailing source such as a motorway upwind of a receiver will be depressed when winds blow in other directions, which will reduce the typical ambient noise level. Is it then appropriate to compare the maximum source noise with a depressed ambient level? If the absolute level is not particularly high then this approach may be unreasonable; alternatively, local weather data could be used to determine the number of days per year when noise is blowing from the new noise source or from other existing noise sources in order to provide a comparison of the different exposures in terms of the number of days affected by each source.

Another factor that might be relevant is the combination of existing and new noise. An existing ambient noise level may not have any adverse impact, but its combination with the intruding noise may lead to circumstances that do. In most situations a cumulative effect is considered unlikely because, either, two equal noise levels will provide a change of 3 dB(A), which will be less than the typical changes expected from day to day due to, say, weather conditions, or the new noise will be significantly higher such that its combination with the ambient noise will be irrelevant. Consideration of a combined effect is only likely to be significant when there are specific and similar tonal characteristics associated with both the new and the existing sources, and also with the hearing or behavioural traits of the receiving animals.

Rain can also alter noise levels at an animal position and torrential conditions will again represent a natural event causing high noise levels that animals have to contend with. The animal's evolution should automatically have catered for a need to withstand such conditions from time to time, and for some animals, e.g. in rain forests, the condition will be present for a much longer period of time. Therefore, the ability to withstand the noise levels generated by such natural conditions should be a reasonable indicator as to whether animals can accept equivalent man-made noise levels, at least on an intermittent basis.

I have recorded noise levels during storm conditions, using the same equipment documented in Figure 4.7, and the results are presented in Figure 4.5. The microphone was at rooftop level close to a hard reflective surface, which would tend to have intensified the noise levels, nevertheless the data indicates maximum levels likely to be experienced by, for example, birds roosting at roof level or animals close to hard surfaces/structures. Noise levels rose steadily as the rain intensified, resulting in an increase of up to 30 dB(A) over ambient conditions without the rain, and an average noise level at the storm's peak of approximately 80 dB L_{Aeq}. The single thunderclap produced a maximum noise level of 95.6 dB(A).

Figure 4.5: Noise levels measured at roof level during a rainstorm with thunder

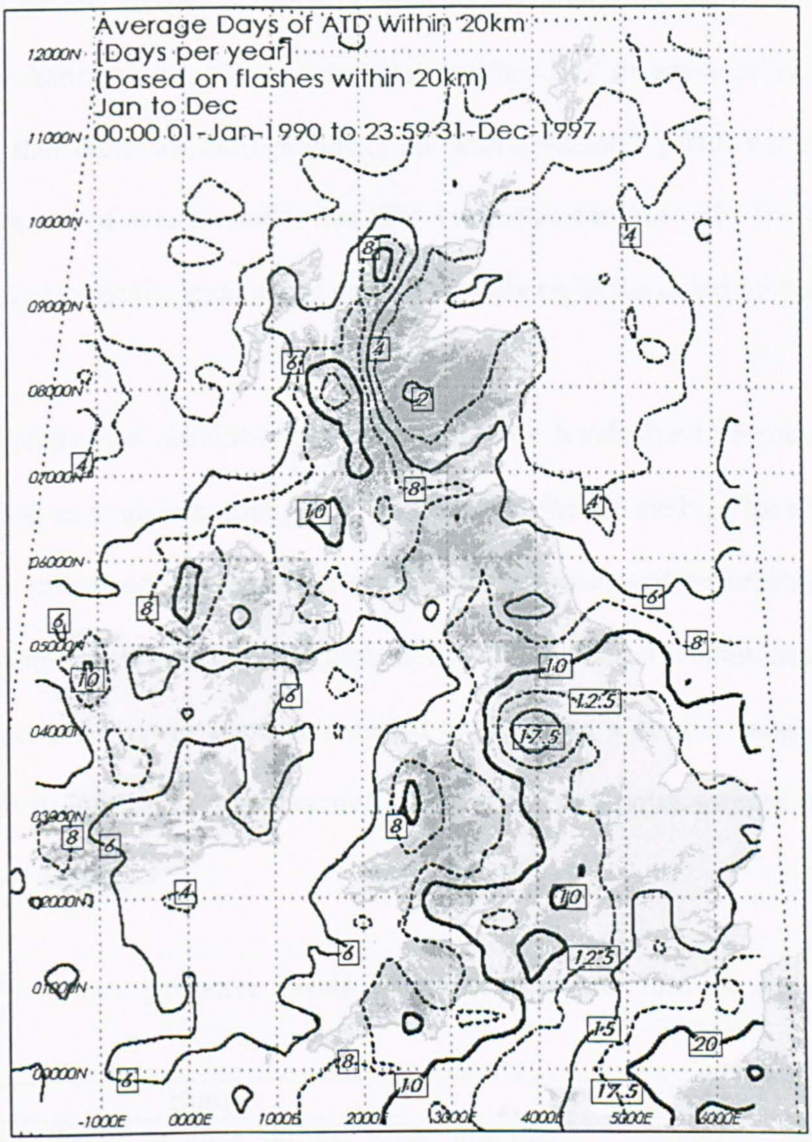


The noise trace in Figure 4.5 shows the high noise levels caused by natural circumstances. More severe conditions will generate higher noise peaks, e.g. due to thunder, as well as more of them. There is no indication of these noise levels causing significant harm to wildlife though there will undoubtedly be some instances of certain animals being startled and perhaps responding in such a way that harm is caused to individuals. Intermittent noise events of equivalent level and duration should, therefore, be capable of being withstood by an animal population without causing any more harm than the equivalent natural noise events.

As a guide to areas affected by lightning, and hence thunder, the Met. Office provide information on the average number of days per year when at least one flash occurs within a 20 km radius, as shown in Figure 4.6. The information is derived from the Met. Office's Arrival Time Difference (ATD) system. A 20 km radius is chosen because it is broadly comparable with traditional 'days of thunder heard' observations on the basis that thunder can be heard up to about 20 km from a flash of lightning. The map provides an indication of how often such high natural noise levels are likely to be experienced by locations within the UK, which can then be compared to any instances of intruding man-made noise levels due to intermittent noise events. Intermittent events might include motor racing circuits used for a few days a year or sonic booms under flightpaths.

In using information such as that suggested above, it may need to be adjusted to suit the specific site circumstances and animals. For example, areas affected will differ according to summer and winter weather patterns. Therefore, when migratory or breeding periods are important it would be necessary to apply the data relevant to that time of the year rather than annual average conditions.

Figure 4.6: The Met. Office's records of average number of days per year when lightning is expected, 1990-1997



Thunder can actually be an important part of a creature's life-cycle by identifying the start of a particular season and triggering a behavioural response. Unfortunately the same sort of response can be triggered by other sources, e.g. ORVs, to the detriment of the animal. For example, the Couch's spadefoot toad (*Scaphiopus couchi*) inhabiting the arid southwestern US, emerge from their burrows to mate and lay eggs when the presence of early summer thunderstorms indicate that external conditions are acceptable. The required conditions are an appropriate temperature to ensure toad survival and availability of prey, and sufficient moisture. The presence of ORVs driving fast across the desert floor causes high levels of low frequency noise, and little attenuation of low frequency noise is afforded by shallow burrows as seen from the study of the kangaroo rat. The consequence of the ORV presence at the wrong time of the year is that the toads emerge during the wrong season[364], with wrong temperatures and an absence of water, which has dire consequences not only for the individuals affected but also for the local population as a whole since the breeding cycle is broken.

The above study also provides information on noise levels due to some natural sources such as wind and rain etc. along with some biotic factors such as local animal noises. This data is presented in Table 4.7 for reference purposes and demonstrates that abiotic factors cause the lowest and highest SPLs under natural conditions. Noise from transmission lines/power plant is reported as covering a similar range as the natural factors, i.e. 20-70 dB(A), whereas most other man-made noise sources tend to generate higher noise levels.

Table 4.7: Sound pressure levels of natural sound sources in a quiet desert habitat[364]

Source	dB(A)	dB(Lin)
Still desert (lowest values during early morning hours, wind 0-5 kph, and only distant insects/birds)	14-27	30-54
Bird wingbeats	30-33	-
Humming bees	29-34	35-38
Walking dog	35-36	-
Trilling toads	36-39	58-60
Walking man	33-40	-
Rainstorm	42-45	50-56
Locust calls	50-56	-
Bird calls	26-60	48-60
Rattlesnakes	24-62	30-62
Rushing streams	50-66	56-68
Windy desert (highest values again during early morning hours but for higher wind speeds, 15-25 kph)	17-38	39-71

4.10 Seasonal and Diurnal Rhythms

It has been noted that temperature, wind speed and humidity conditions can significantly affect the noise level at an animal's position due to gradients in each condition that can occur close to the ground. These conditions change both daily and seasonally, which makes it important to evaluate the effect they could have with respect to a species' diurnal or seasonal behavioural traits

It is also relevant that within a given community, for example a tropical forest environment that is renowned for being a noisy environment due to communications occurring between a large number of different species, there may be different daily patterns of sound communication[365]. In effect, many species stagger their vocalisations throughout the day to avoid acoustic interference. Therefore, in assessing the impact of a noise it will be important to study those animal species that will be actually calling, and hence also listening, at the time of the noise events. Other methods used by animals to prevent acoustic interference include patterns of notes, temporal variations and frequency modulations.

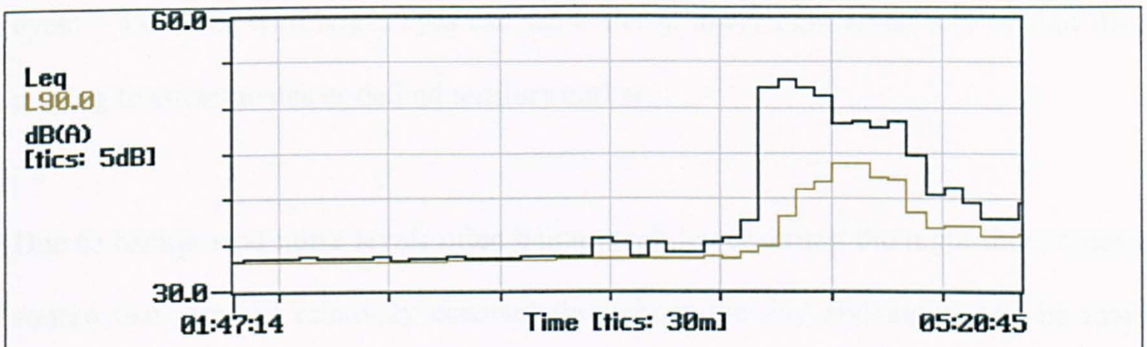
The adverse impact of noise at an inappropriate time of the year has been demonstrated by reference to ORV noise causing the emergence of the spadefoot toad at a time of year inappropriate for them to thrive and breed. Similar effects have been observed due to ORV noise disrupting the courtship and breeding of desert birds[324]. The avoidance of any conflict between noisy activities and sensitive breeding seasons is one of the main mitigation measures used to protect sensitive species. It is peculiar, however, that in the case of the spadefoot toad, the noisy activity would seem more appropriate during the sensitive breeding season. Therefore, this mitigation approach can only be applied with caution and with a knowledge of the behavioural characteristics of the animals being exposed to noise.

One aspect of diurnal rhythms is the noise that the animals themselves may make and how this compares to intruding noises. Birds are renowned for their dawn chorus, which in rural areas can often cause people to be wakened. Figure 4.7 shows measurements I undertook firstly at a rural farm location comprising farm buildings and barns etc., and secondly in fields with trees, bushes and hedgerows at the edge of suburban development.

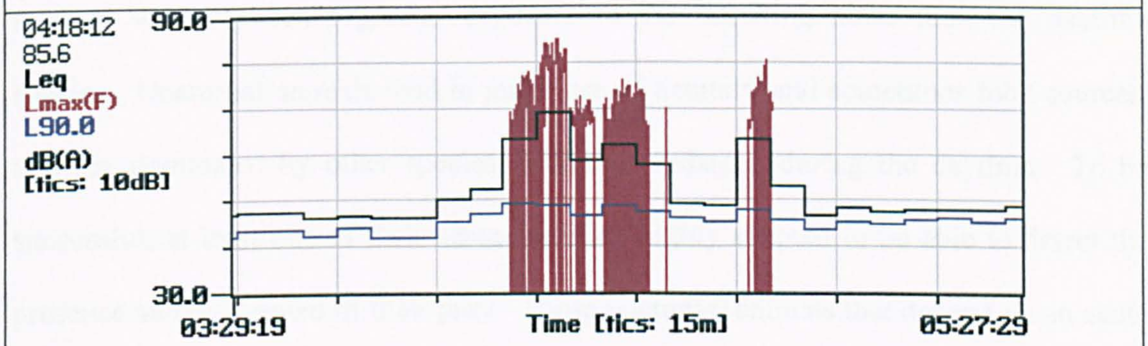
The first noise trace shows the L_{Aeq} and L_{A90} noise levels to be virtually identical at night-time; these were typically 36, 37 and 34 dB over three successive nights. The dawn chorus commenced at approximately 0415 hours and lasted for approximately 45 minutes and each morning produced maximum $L_{Aeq\ (5\text{-minute})}$ noise levels of 53-54 dB and L_{A90} levels of 44 dB, i.e. increases respectively of 17-20 and 8-10 dB.

The second trace also displays maximum noise events that exceeded a threshold level of 65 dB(A), and show that the chorus commenced at approximately 0410 hours and again continued for 30-45 minutes. At this location, the background noise level did not exhibit the same rise, which suggests fewer birds were present and hence less continuous calling, but the L_{Aeq} levels increased from approximately 48 to 65-70 dB, a rise of more than 15-20 dB in the vicinity of the birds, and L_{Amax} levels reached 86 dB.

Figure 4.7: Noise levels measured during early morning dawn chorus due to bird song



Rural Farm



Field at edge of suburban development

Equipment:	CEL-90249 eNVi system hardware with NoiseMaster software; CRL MV 181A Pre-amplifier and cable; MK 224 Precision ½ inch electret condenser microphone + windshield; Psion Series 3c organiser to log and display data; and Larson Davies CA200 acoustic calibrator. Calibration: 94 dB

The microphones were located at a height of 1.5m above ground level in a free-field location and the birds were located on farm buildings, trees, bushes and fences spread around the measurement point. At locations closer to groups of birds the noise level would be significantly higher, e.g. 70 dB L_{Aeq} or higher, which provides a useful measure of noise levels that clearly do not cause harm because they are a natural element of the daily behaviour patterns, and it also provides a pointer towards a trigger level for assessment purposes. The start time and duration of the dawn chorus will vary with the location, the season and the bird population. Recent research has shown that different species will sing at different times dependent upon the size of the birds' eyes[366], i.e. birds with larger eyes can see better at lower light levels and so start their singing to attract mates or defend territory earlier.

Due to background noise levels often being much lower during the night-time, a noise source that remains relatively constant throughout the day and night may be more noticeable and more disturbing during the night-time. In such cases, all nocturnal animals will experience greater exposure to the intruding noise than the daytime species. Nocturnal animals tend to make use of habitats, and sometimes food sources, that are dominated by other species, possibly predators, during the daytime. To be successful, at least one of their senses is often highly adapted to be able to detect the presence and movement of their prey. Those nocturnal animals that depend on an acute sense of hearing will be most sensitive to environmental noise.

In the UK, nocturnal animals comprise the hedgehog, dormouse, harvest mouse and wood mouse, pine marten, wild cat, badger, bats, woodcock, nightjar, barn owl and long-eared and tawny owls. The fox, nightingale and frogs and toads are also particularly active at night-time, as are various insects. Outside the UK, other nocturnal animals include leopards and tigers, nighthawks, civets and mongooses, wild boars and skunks; many desert reptiles such as pit vipers and lizards avoid the heat of the day by burrowing or sleeping in the shade and emerging at night-time. Many desert mammals similarly burrow in the ground to avoid the desert heat and come out at night to feed, and they include jerboas, gerbils, rats and mice. Some spiders, e.g. trapdoor and bird-eating spiders are also night-time hunters. Scorpions in turn hunt spiders, centipedes and insects at night, and small tree-living mammals such as tree-shrews and lorises also feed at night.

Night-time noise may not only have a direct impact on animals due to their hearing sensitivity but it may also have an indirect effect on their ability to detect prey. For example a barn owl will use its sensitive hearing to detect the movement of small prey such as mice and voles on the ground below its perch. However, a continuous noise that caused the background noise level to be raised might be sufficient to acoustically 'hide' the sounds of prey from the owl. A loss of auditory sensitivity might result in a lower food intake and greater energy expenditure, which if maintained long-term could have an adverse impact on individual animals or affect the suitability of a habitat for a given species.

There is insufficient evidence to establish whether all or some nocturnal animals will definitely be more sensitive to a given noise at night-time than other animals exposed to the same level of noise during the day. In terms of human annoyance, there is certainly a basis for a greater sensitivity towards noise at night-time and the use within various international noise assessment procedures of a 10 dB weighting towards night-time noise. However, there is a difference for animals because whereas humans at night are generally looking for a quieter period to enable the restorative process of sleep, nocturnal animals are active and are looking for sources of noise within a quiet climate to provide them with information on the presence of other animals. Further research is required to ascertain whether night-time noise exposure for nocturnal animals, or indeed for other species in the process of sleeping/roosting, needs a weighting factor to reflect effects that would not otherwise materialise during daytime exposure.

4.11 Energy Expenditure

Energy expenditure is unlikely to be routinely measured or calculated as part of the assessment process, but it nevertheless is an important element of any assessment because it will determine how well an animal recovers from exposure to noise. Energy will be expended in physiological as well as behavioural responses, and the amount of energy lost will often be influenced by some of the other factors discussed in this section.

Simple formulae for estimating the energy cost of locomotion in calories have been proposed[97] based on a hypothesis that the energy cost per unit mass per unit of locomotion (e.g. a step) is constant. The data used indicated that swimming is more energy efficient than flying, which in turn is more efficient than running. (The proposed formulae for estimating energy cost were 4 x 10^{-5} calories/gm of body mass/'stroke' for swimming, 1 x 10^{-4} cal/g/'flap' for flying and 3 x 10^{-4} cal/g/'step' for running.) The energy cost in running animals[660] has been found to be generally independent of speed such that the amount of energy used per unit of distance is approximately the same whatever an animal's pace. At higher speeds, energy is used more rapidly but the total energy cost/unit of travel tends to remain similar.

Snow geese experience both increased energy expenditure and decreased energy intake in response to aircraft or other disturbances that cause them to take flight. When the disturbance was at a rate of 1.5/hour, the birds were able to compensate by feeding at night when the noise was not present, thereby recovering the lost energy. However, if the birds were actually flushed from their feeding area, they needed to feed for 32% of the night, which represents a significant time commitment to feeding at a time when the birds would normally be resting. In the latter case, although the birds were able to compensate for the lost feeding time, the overall impact is likely to represent an energy imbalance.

In the case of ground animals, the presence of snow is also likely to cause increased energy expenditure during flight from a noise source, especially if the snow is deep or the animal is small but heavy enough to break the snow's surface. For marten that have little body fat for storing energy, digging through snow to get small prey will also involve extra energy expenditure. Small mammals may also show different startle responses according to whether they are in a burrow or outside at the time of exposure. Outside the burrow, the animal is likely to exhibit an increased heart rate ready for flight, which will incur greater energy expenditure. However, inside the burrow the response is more likely to be a decrease in heart rate and breathing, which would incur less energy expenditure.

4.12 Summary

The information provided in this chapter is intended to provide guidance on matters that may need to be considered when assessing the effect of environmental noise on animal communities. It is not suggested that all the matters mentioned will be required for every assessment, rather, the information is intended to assist with the assessment process and identify precautions or methods that may need to be taken. The chapter also seeks to demonstrate how noise might behave within, or inter-relate with, an animal's environmental conditions, and to show that the final impact might often depend on quite obscure, or what might appear to be minor, factors that may need to be identified in order to secure a robust and accurate assessment.

5. PROPOSED PROCEDURES FOR ASSESSMENT

This chapter seeks to pull together the information presented so far in order to present a set of procedures that can be used whenever a new development may potentially impact upon animals. In the absence of formal guidelines for assessing the impact of noise on animals, it would be helpful to know whether there are specific noise level thresholds or distance thresholds, either applicable to animals as a whole or to different species, which could be used to denote that impacts are either acceptable or adverse. Also, for many people either undertaking EAs or judging the potential impacts, it would also be helpful to have guidance both on the type of assessment required to adequately judge the impact and the scale of the effect on individual animals or local animal populations.

UK planning policy guidance on noise can be found in PPG24 Planning and Noise[367], in which land proposed for new residential development and affected by transportation noise (road, rail or aircraft noise), or a mix of transportation and industrial noise, is assessed in terms of Noise Exposure Categories (NEC). Four NEC categories are defined in terms of L_{Aeq} noise levels, which are used to define the suitability of sites for residential purposes. A daytime threshold of 72 dB $L_{Aeq\ (16\text{-hour})}$ (NEC D) is used to define land that is not suitable for residential use. The other three categories are used to define the level of noise exposure with a view to evaluating the amount of noise mitigation that would be required in order to make the land acceptable for residential use.

If a noise threshold or noise bands can similarly be defined for effects on animals, this would remove some of the uncertainties presently surrounding the potential impacts on animals, and simplify the assessment process. Ideally, a threshold value could in the first instance determine whether assessment is or is not required. Thereafter, a set of noise exposure categories or set of standard procedures would determine the extent of assessment that would be required to enable impacts to be quantified. Alternatively, the distance between an animal and the noise source might also provide a means of determining whether an assessment is required or the extent of the assessment.

5.1 Analysis of Animal Responses

In order to analyse the broad spread of documented responses of animals to noise, a summary table of animals, noise sources and responses has been drawn up and is presented in Appendix VI. Information is presented in ascending taxonomic order for different classes of animals. The information represents the majority of the commonly referenced papers where an animal response to a specific source or level of noise has been identified. There are numerous other papers dealing with specific issues such as vocalisation characteristics of particular species, most especially for insects and birds, but these have not been included because they do not provide material relating to actual behavioural responses to noise. Different farm animals are included within the main table of responses at the appropriate point in the animal tree, however, due to the often particular interest in farm animals as a group, these animals have also been separated for reference purposes within a second table in Appendix VI that relates solely to farm animals.

Of the total of 348 recorded animal responses in Appendix VI, only 7 (2.0%) relate to insects, 1 (0.3%) to crustacea, 1 (0.3%) to sharks and rays, 23 (6.6%) to bony fishes, 4 (1.1%) to amphibia, 7 (2.0%) to reptiles, 148 (42.5%) to birds and 156 (44.8%) to mammals. Within the total, 44 (12.6%) relate to farm animals, ranging from ostriches to goats. A recent review[368] of noise effects on animals reports few studies on terrestrial mammals since 1996, very few studies at all on terrestrial and aquatic reptiles and fish, which is basically consistent with the above breakdown, but increasing studies relating to marine mammals. Habituation is also described as poorly investigated. In some respects, the above proportional breakdown reflects the sensitivity of the different species to noise. Although the proportional split for insects is relatively low, there is in fact a wealth of research papers relating to insect vocalisations, e.g. cricket calls, and their transmission within different habitats, but little information is available on the possible interference effects of man-made noises. However, due to the relatively short communication distances for insects, intruding noise would need to be particularly excessive over a large area for it to have any significant effect on insect populations, and such circumstances are improbable. Hence, there is little interest in the effects of noise on the species.

From the animal classifications covered by the literature summarised in Appendix VI, it is evident that only a small proportion of the animal kingdom has been considered as sensitive to man-made noise. This may not be unreasonable since the phyla not covered tend to be low on the evolutionary scale, or to have no sensory organs capable of responding to noise and/or vibration, or are not significant with respect to environmental considerations. Animals that can probably be ignored in this way will include sponges, hydras, jellyfishes, corals and sea-anemones, comb jellies, free-living flatworms, flukes, tapeworms, ribbon worms, round worms, rotifers, horsehair worms, spiny-headed worms, bryozoans, lamp shells, snails, tusk shells, bivalves, squids and octopuses, marine segmented worms, earthworms, leeches, millipedes, and centipedes. It is noticeable that this list largely comprises animals living in water or soil, or as parasites, which will in any event reduce their exposure to sounds transmitted through the air. However, it cannot be assumed that there will never be a situation when noise or vibration impacts may be of concern with respect to localised communities of some of the above animals. For instance, there could be construction activities such as piling, which would generate both noise and vibration, close to beds of marine bivalves that might have local significance.

Other animal groups not obvious within the research studies include spiders, ticks, scorpions, horseshoe crabs, sea spiders, starfish, brittle stars, sea urchins and sand dollars, sea cucumbers, sea lilies, sea lancelets, amphioxus, tunicates, jawless fishes (hagfishes and lampreys) and chimaeras. Again, the majority of these live in water or are not significant with respect to environmental considerations. The main animal classes likely to be of concern with respect to environmental noise will, therefore, be mammals and birds, and to a lesser extent fish, reptiles and amphibia. Insects may be of occasional interest subject to circumstances relating to the type of insect, the noise source and the locality/habitat.

When it comes to deriving appropriate noise limits for the sensitive species, the listed responses highlight the difficulty in defining specific noise levels that will elicit specific responses because few of the studies to date actually clearly record the absolute noise levels experienced by each species. When a noise level is recorded, the type of noise index, e.g. L_{Aeq} or $L_{N\ values}$, or the frequency weighting, may not be identified. Units that are recorded, e.g. overpressures due to sonic booms, are often different from one study to another. In many cases, the type of noise source is identified but the noise level generated is not. In others, different responses have been recorded for the same species, which makes it difficult to determine whether either one is likely to be pertinent to a different location/situation. Wherever possible, the information in Appendix VI is presented using the units used by the researchers, but standard metric units are presented in brackets along with conversions to a sound pressure level where this is applicable. The various conversion factors are noted at the end of the Appendix.

Since there are no clear indications that specific noise criteria can be developed for assessment purposes, and what information there is shows widely differing reactions, often within the same species, a further analysis has been undertaken by assigning an assessment criterion to each response. For this purpose, three distinct criteria were chosen and are aimed at identifying slight, moderate and severe responses. In addition, a fourth category of 'no effect' can be included where the exposure to noise has produced no noticeable impact. The definitions of the criteria are described in Table 5.1 and have been developed solely for the purpose of this analysis. However, it can be seen that the various components used to define each of the categories are relevant to the significance of the response and are key factors to be considered in any assessment when the overall significance of an exposure needs to be gauged.

Table 5.1: Significance criteria developed to assess animal responses to noise

Category	Definition
No effect	Exposure to noise produces no recorded effect.
Slight	Noise causes a reaction, whether physiological or behavioural, but animal returns to pre-exposure conditions relatively quickly and without continuing effects. The reaction may include movement such as flight or running away from the source but not to the extent that animals leave home territory. The response may also involve increased energy expenditure but not to the extent that it cannot easily be recovered after exposure. An example of a noise exposure that could produce startle reactions but allows recovery is a single aircraft overflight, since the event is limited in time and allows ample time for recovery either between individual events or on other unaffected days.
Moderate	Noise will cause many of the responses observed under the 'slight' category but they are carried a stage further by causing more permanent changes that do not allow individuals or communities to readily return to pre-exposure conditions. For example, exposure to more frequent aircraft overflights may cause animals to leave their home territory or feeding grounds permanently; or lead to decreased feeding, fertility or reproductive rates; or reduce flock sizes or population numbers. Noise sources that lead to loss of hearing sensitivity are likely to increase the risk of adverse effects. The long-term consequences may be uncertain, for example if sustained they could lead to harm to individuals and to local communities, which would eventually be a severe response, but such adverse effects are not immediately obvious.
Severe	This category defines situations where noise exposure has produced demonstrable harm, either injury or death, to animals. It covers situations where individuals within larger groups are affected by either injury or death, which will not affect the viability of the species as a whole, to situations where the effect is sufficiently widespread to cause decline within the local population. Nest abandonment has been included in this category because it means the death of the potential offspring and probably reduced population numbers. Temporary abandonment of a nest would not be included. Levels or frequencies of noise that cause abnormal behavioural responses, such as emergence from hibernation during inappropriate seasons, are likely to lead to severe responses.

The definitions assigned to the assessment criteria are such that for the 'no effect' and 'slight' categories, these respectively reflect no effect at all or only temporary and non-harmful effects. Therefore, for impact assessment purposes, no specific mitigation measures would be required to protect animals from exposure to levels of noise that generated responses assigned to these two categories. In contrast, the categories of 'moderate' and 'severe' are associated with permanent or harmful responses, which would require the application of mitigation measures in order to protect animals from adverse effects. The use of the criteria to determine the acceptability of noise and the need for mitigation is tested in Chapter 6. In those situations where the response is not sufficiently clear cut between slight and moderate, or where there may be uncertainties whose effects cannot be defined, pre-cautionary or observational measures may be required in the interim to ensure that effects do not shift into the moderate category, which would then require definite mitigation measures. Discretionary mitigation would also be permissible in those categories where it is not compulsory.

The above assessment criteria have been assigned to the responses listed in Appendix VI using the following codes – 'O' denotes no effect, 'S' = slight, 'M' = moderate, and 'SV' = severe. The resulting totals for each category are presented in Table 5.2. The information has again been split into that for all animal classes, with a separate analysis for farm animals only. No code has been applied to studies that provide details of hearing sensitivities rather than responses to actual noise exposure, therefore, the totals are slightly less than the total responses presented in Appendix VI.

Table 5.2: Analysis of recorded animal responses from literature review

All Animals				
No effect	**Slight**	**Moderate**	**Severe**	**Total**
41	223	70[1]	16[1]	350
Farm Animals				
No effect	**Slight**	**Moderate**	**Severe**	**Total**
7	34	2	1	44

Note: 1. 2 responses were classed as borderline between moderate and severe and have been counted therefore within both categories and within the total.

The categories of 'no effect' and 'slight effect' have no long-term adverse impact on individual animals and their local population numbers, and they represent by far the largest proportion of the total responses (75% in the case of all animal classes and 93% for farm animals). On the assumption that the documented animal responses are fully representative of the range of cause-and-effects within the animal kingdom, the indication from the above analysis is that there is only a relatively small risk of noise being likely to cause adverse long-term effects on animals. This conclusion is consistent with the difficulty I found in locating a situation where adverse effects due to noise were known to arise for the purpose of testing the validity of the proposed assessment procedure (see Chapter 6). Nevertheless, severe effects can arise and it is important to be able recognise these so that appropriate measures can be undertaken before irreversible damage has been caused.

Of the responses for all animal classes, 84 of these out of 348 (24%) were in the moderate and severe categories (excluding the two duplicated responses), therefore, the risk of an adverse response from exposure to man-made noise would appear to be almost 1 in 4. Farm animals seem to be less sensitive because the risk of an adverse response using the above data is 1 in 15 or nearly 7%. This lower sensitivity to noise is consistent with a domesticated background and the fact that farm animals will have evolved alongside man's activities and on a day to day basis will often be exposed to noise from farm machinery. Nevertheless, the National Farmers' Union of England and Wales has suggested that certain classes of livestock will always be sensitive to noise, and in relation to noise from low-flying aircraft have identified poultry and other housed animals, pregnant and sick animals, and horses and dogs as being particularly sensitive[369]. They relate severe effects causing injury or death to instances of stampeding when this involves attempted penetration of barbed wire fences, to abortions of pregnant animals, and to smothering of intensive poultry, although there appears to be little published evidence to suggest that such responses are anything but rare.

Animal's living in denser groups and housed inside farm buildings will also often be subjected to higher background noise levels due to the numerous vocalisations etc., often within a sound reflecting or reverberant structure, and the presence of noise from ventilation fans and other service machinery. Studies on the domestic pig[370] have shown the average sound pressure level in mechanically ventilated pig buildings to be 73 dB(Lin) and the average for naturally ventilated buildings to be 10 dB lower, i.e. approximately 63 dB(Lin). On the assumption that there is no significant extraneous noise such as road traffic, the latter noise level is likely to be largely influenced by pig vocalisations. During transport, noise levels were found to increase to an average of 93 dB(Lin), which would be due to a combination of vocalisations, vehicle noise and turbulent air flows around and through the vehicle. The long-term exposure of farm animals to noise from group vocalisations, along with noise from other farm activities and servicing machinery, is likely to lead to a degree of habituation to noise in general (see Chapter 2, page 46).

One can take the analysis of animal responses one step further by considering the types of responses within the different animal Classes to see whether there is any obvious sensitivity associated with specific animal groups. This breakdown of responses is presented in Table 5.3. Where animal Classes comprise a large number of studies, i.e. birds and mammals, further subdivision is provided where appropriate for different Orders and Suborders. Not all animal species are covered by the research studies, therefore, not all Classes, Orders and Families are presented in the Table.

Table 5.3: Classification of animal responses from literature review

Classification	Animal	Response				
		No Effect	Slight	Moderate	Severe	Total
Class Insecta	Locust, moth, midge, bee	1	2	4	0	7
Class Crustacea	Shrimps	0	0	0	1	1
Class Pisces	Bony fish	4	13	4	2	23
Class Amphibia	Toads, frogs	0	3	0	1	4
Class Reptilia	Tortoise, iguana, lizard	0	2	3+(2)	(2)	7
Class Aves	Birds					
Orders Struthioniformes, Rheiformes, Casuariformes and Sphenisciformes	Ostrich, rhea, emu and penguin	0	1	1	1	3
Order Gaviiformes	Divers and loons	1	1	2	1	5
Order Pelecaniformes	Pelicans	0	0	0	2	2
Order Ciconiiformes	Herons and storks	1	2	0	0	3
Order Anseriformes	Ducks, geese and swans	1	33	14	2	50
Order Falconiformes	Birds of prey	9	21	3	2	35
Order Galliformes	Fowls, turkey, pheasant	6	9	1	0	16
Order Gruiformes	Cranes and rails	1	2	0	0	3
Order Charadriiformes	Waders and gulls	3	3	1	1	8
Order Columbiformes	Pigeons and doves	1	0	0	0	1
Order Psittaciformes	Parrots and parakeets	0	0	1	0	1
Order Strigiformes	Owls	0	4	0	0	4
Order Piciformes	Woodpeckers	2	0	0	0	2
Order Passeriformes	Perching birds	2	10	3	0	15
	Bird totals	**27 (18.2%)**	**86 (58.1%)**	**26 (17.6%)**	**9 (6.1%)**	**148**
Class Mammalia	Mammals					
Order Primates	Monkeys	0	2	0	0	2
Order Lagomorpha	Hares, rabbits	0	4	1	0	5
Order Rodentia	Chinchillas, squirrels, rats, mice	0	17	11	1	29
Order Cetacea	Whales	0	7	0	0	7
Order Carnivora	Flesh-eaters					
Suborder Fissipeda	Dogs, mink, cats, bears	0	14	3	0	17
Suborder Pinnipedia	Seals, sea-lions, walruses	0	10	1	0	11
Order Perissodactyla	Odd-toed ungulates (horses, asses, zebras)	0	2	0	0	2
Order Artiodactyla	Even-toed ungulates (pigs, cattle, sheep, deer)	9	59	15	0	83
	Mammal Totals	**9 (5.8%)**	**115 (73.7%)**	**31 (19.9%)**	**1 (0.6%)**	**156**

Birds account for a slightly smaller number of studies than mammals, yet they have been assigned slightly more severe responses, 9 as opposed to 1 in mammals, which suggests that perhaps birds are likely to be more sensitive to noise. The number of moderate responses are 26 for birds and 31 for mammals, which, bearing in mind the smaller total for birds, suggests a similar sensitivity in this category. However, particular caution must be used when generalising in this way because unaccounted factors might easily tip a slight response into a moderate or a moderate into a severe. Long-term effects might work in this way. Equally, habituation could change a short-term moderate effect into a long-term slight effect. However, for assessment purposes long-term trends that cause categories of impact to be downgraded will be beneficial and can for this reason be ignored. The primary concern must be to prevent adverse impacts and any worsening of these with time, therefore, it is the risk of upgrading an impact that must be considered within an assessment.

For many animals, there are insufficient study results to be able to conclude without doubt that noise will or will not cause adverse responses. In any situation, there are likely to be different relationships between the animals, their habitats and the noise sources, which will influence their response at that time. Even given similar exposure circumstances it cannot be assumed that the response will be the same as that documented. Nevertheless, it may be possible to identify species that are less sensitive or have a greater resilience to noise. For instance, animals that have not exhibited a severe response and which also have a low number of moderate responses coupled with significantly more slight or no effect responses, should be indicative of a less sensitive or resilient species. Applying this approach to the data in Table 5.3, animals that can be identified in this way are herons and storks, fowls, turkeys, pheasants etc., cranes and rails, pigeons and doves, owls, parrots and parakeets, perching birds, monkeys, whales, seals, sea-lions and walruses, and many types of ungulates.

Further important information relating to the causes of adverse responses can be obtained by reviewing those responses classed as severe. This information is presented in Table 5.4 and regard should be had to the reasons used to define a severe response in Table 5.1.

The information given in Table 5.4 about the shrimp can be ignored for assessment purposes because, as with many laboratory experiments, the noise was artificial and the animals were confined. Since the animals could not leave the area of noise exposure as they can in the wild, the information does not reflect natural circumstances. Artificial laboratory exposures also often use high and sustained noise levels that equally do not reflect natural events. Of the remaining responses it is immediately obvious that one set of circumstances dominate, namely the effects of noise from ORVs on animals within the quieter desert or scrub regions, which amount to 25% of the total responses. The animals affected in this way are toads, iguanas and lizards, and kangaroo rats; other species having similar behavioural characteristics can be expected to react in similar fashion.

The remaining severe responses mainly relate to birds exposed to aircraft noise, whether it be aircraft or helicopter overflights or sonic booms. The species of birds found to be affected were ostrich, emu and greater rhea, pelican, tundra swan, snow goose, peregrine falcon, gyrfalcon and sooty tern. This does not mean that only these species will be affected or that they will always be affected, but that the circumstances contributing to their noise exposure caused adverse responses at that time. The indications are that at other times the animals may respond to a lesser extent, or that other species could possibly be affected to a similar degree. Three severe responses that did not fit the above pattern were the effects of sonic booms and pile driving on fish and motorboats on the common loon.

Table 5.4: Details of animal responses from literature review that have been classified as severe

Animal	Noise source	Response
Shrimp	Artificial	Significant reduction in growth and reproductive rates
Striped bass	Sonic booms	Fish deaths due toseizures/jumping out of water
Fish (anchovy, herring, sardine, surfperch)	Pile driver	Fish deaths – ruptured blood vessels and swim bladders
Spadefoot toad	ORV	Elicits emergence from burrow with potentially deadly consequences if occurs at inappropriate time of year
Desert iguana	ORV	Permanent threshold shift
Mohave fringe toed sand lizard	ORV	Temporary threshold shifts even when animal buried under shallow layers of sand
Ostrich, emu and greater rhea	Aircraft overflights	Fatalities, injuries, breeding decline and stress
Common loon	Motorboats	Eggs lost from nest and not replaced after disturbance
Pelican	Aircraft overflights	Stampede, panic, eggs lost, abandoned and eaten
Pelican	Aircraft overflights	Panic resulting in lost eggs and young
Tundra swan	Helicopter disturbance	Birds flushed and abandoned nests
Snow goose	Helicopter overflights	Parents driven from nests for up to 45 minutes allowing gulls to prey on unattended eggs
Peregrine falcon	Helicopter (<2000ft)	Severe response
Gyrfalcon	Aircraft overflights	13 of 27 active nests deserted during early nesting period
Sooty tern	Daily sonic booms from jet aircraft	98% reduction in reproduction of colony
Kangaroo rat	ORV	Hearing impairment lasted for up to 3 weeks

The above analysis at least enables specific situations to be identified, which can then be used as a form of screening to determine when an assessment should be undertaken. The key factors can be identified as follows:

- presence of noise from ORV vehicles, e.g. trail bikes, dune buggies etc.;
- animals within a normally quiet and open habitat, e.g. desert and scrubland;
- presence of animals that have developed specific characteristics that provide unusual hearing sensitivities or behaviours, e.g. spadefoot toad and kangaroo rat;

- situations that involve birds and noise from fixed wing aircraft, helicopters, sonic booms or motorboats; and
- effects of intense impulse noises on fish.

Further identification of key factors has been sought by categorising the moderate responses into different types of noise source. Only environmental responses as opposed to laboratory situations or responses to unspecified noise sources have been considered and the break down is presented in Table 5.5. Many studies of aircraft noise referenced the noise source as comprising both fixed wing aircraft and helicopters. In such cases, a moderate response was counted in both the aircraft and helicopter categories. The aircraft category encompasses all types of fixed wing aircraft from small single engine planes, through civil aircraft to supersonic military jets. The significance of noise from aircraft sources is again reflected in the analysis of moderate responses because 79% relate to fixed wing aircraft, helicopters and sonic booms.

Table 5.5: Types of noise sources classified from the literature review as producing moderate responses

Source	Number
Fixed wing aircraft	26
Helicopters	18
Sonic booms	8
Blasting/drilling/air gun	5
Boating	4
Off-road vehicles	2
Human presence	2
Railway	1

Since the published response data is being used to develop what are intended to be formal assessment procedures, it is important to establish the credibility or confidence rating of the data being analysed. To do this I have also assigned a credibility rating to each response within Appendix VI using the scale defined in Table 5.6.

Table 5.6: Credibility rating scale for reported animal responses

Scale	Definition
1	None – no relevance to environmental assessment procedures.
2	Low – Neither noise source nor animal response are clearly defined.
3	Medium – Response qualified but noise threshold cannot be defined with certainty.
4	High – Both response and noise level are clearly defined.
5	Maximum - As for rating 4 but also confirmed by other studies.

The number of responses within each rating have been summed, as have the number of 'no', 'slight', 'moderate' and 'severe' effects within each rating band, and the results are presented in Table 5.7. In this analysis, the two responses previously identified as falling between moderate and severe have been counted separately, and other items in Appendix VI that were not assigned significance criteria and have no relevance to the development of assessment procedures have not been included.

Table 5.7: Relationship between significance criteria and credibility ratings

Total	Credibility Rating	Significance Criteria				
		O	S	M	(M/SV)	SV
3	1	0	3	0	-	0
13	2	2	10	1	-	0
189	3	24	114	44	-	7
109	4	8	76	21	-	4
34	5	7	20	2	2	3
348	**Totals**	41	223	68	2	14

Only 16 or 5% of the responses fall within the lowest credibility ratings that have either no or low relevance with regard to setting the assessment procedures. The majority of the responses, 189 or 54%, fall within the medium category in which the response was qualified but the noise threshold could not be defined with certainty, but this is to be expected since the majority of responses likewise fell into the slight category where adverse or long term effects do not arise. 109 or 31% fall within the high credibility rating for which both the response and noise level are clearly defined, and a further 34 or 10% had the maximum rating by being confirmed by other studies, making a total of 143 or 41% responses that provided clearly credible data for developing the assessment procedures.

Since the key factors for assessment (see paragraph following Table 5.4) have been developed largely from the category of severe responses, those that also have a credibility rating of 4 or 5 within this category will provide additional confidence in the use of the assessment triggers. Responses having the maximum credibility rating of 5 relate to hearing loss/damage caused by ORVs on lizards and kangaroo rats in quiet desert areas, and to panic caused to pelicans by aircraft overflights; rating 4 in this category applies to the inappropriate emergence of spadefoot toads from their burrows, again due to ORVs, and the effects of intense impulse noise on fish. Therefore, all of the key factors that the proposed assessment procedure builds upon, i.e. presence of noise from ORV vehicles, animals within a normally quiet and open habitat, presence of animals that have unusual hearing sensitivities or specific behavioural characteristics, situations that involve birds and aircraft, and effects of intense noise on fish, do have a high credibility rating.

With regard to a trigger for situations that involve birds and noise from fixed wing aircraft, helicopters or sonic booms, most of the remaining severe responses having a rating of <4 establish recognised responses to low-flying aircraft, helicopters and sonic booms, with generally much stronger responses caused by exposure to helicopters.

These confirmed responses provide further credibility for inclusion of this trigger within the assessment procedure.

Although the above analyses have looked at the results from a finite number of papers, it is not the numbers per se that have been used to form the basis of an assessment methodology. Rather, it is the responses attributed to reported combinations of a named source, named animal and noise exposure. Having identified the main noise sources likely to cause responses in animals, and the species most likely to be adversely affected, specific factors have also been sought by reviewing the animal responses by the different taxonomic classes listed in Appendix VI. In particular, evidence for a screening threshold has been sought, in terms of either a noise level or separation distance that can be used for those situations not covered by the assessment triggers described above having the highest credibility ratings.

No significant conclusions can be drawn from the responses for insects, crustacea and sharks/rays due to the very limited information available. Responses were observed, such as changes to the degree of movement (both increased and decreased movements for insects) but noise levels were higher than environmental levels of noise and the animals were captive. In the wild, most animal species will have the ability to move away from a noise source if it is causing them distress; any adverse impact will then depend on matters such as energy expenditure that cannot readily be replaced, loss of feeding or breeding habitats, and fragmenting of communities.

5.2 Fish

Fish, as for other animal classes living in water, are largely protected from airborne sounds due to the relatively small amount of sound energy that is transmitted from one medium to another. Even in the case of sonic booms, although slight behavioural responses may be observed, these appear to largely have no long-term or adverse effect. The range of pressures recorded were identified by researchers as 'mild', up to 4.16 psf, >1 mbar and 0.26 atm, and the different units illustrate the difficulty of comparing different responses and relating given circumstances to other scenarios. If fish, or other underwater creatures, are to be adversely affected due to noise, this is most likely to arise from sources generating noise within the water itself, e.g. from construction activities such as dredging, piling, blasting or from research/military testing such as ATOC and SURTASS. The latter two sources generate higher noise levels than most other underwater sources such as ships' engines and construction, but underwater seismic explosions generate the highest levels as shown in Table A4.1 of Appendix IV. The recorded severe impacts on fish relate to those instances when intense sounds are applied directly into the water, namely intense focused sonic booms or pile driving.

The exposure limit applied to marine mammals is a Received Level (RL) of 140 dB re 1μPa rms, although no adverse responses have been observed up to levels of 155 dB. The referenced study on rockfish exposed to a RL of 153 dB re 1μPa rms similarly found no significant response, although intense white noise at 158 dB re 1μPa for periods of 12 and 24 hours has been found to cause significant hearing loss in goldfish and catfish[371], with hearing thresholds recovering after 3 and 14 days respectively.

Therefore, the limit of 140 dB applied to marine mammals would seem equally relevant to fish.

5.3 Amphibia

Responses in frogs and toads are largely confined to acoustic avoidance behaviour, i.e. they will time their calls so that they do not conflict with other noises. Apart from this, noise does not appear to have a significant impact. However, one species – the spadefoot toad – is particularly susceptible to low frequency noise at inappropriate times of the year, i.e. when exhaust noise from ORVs causes hibernating toads to believe that the thunderstorms indicative of the start of the breeding season are present. The sounds (a level of 95 dB(A) is reported) cause the toads to leave their burrows during weather conditions that do not have the requisite degree of temperature and humidity for normal survival, which can have harmful consequences for individuals or indeed significant effects on local populations.

The response of the spadefoot toad to a specific noise source is indicative of the occasional unusual effect that does not fit the common responses for other members of the class. A similar situation arises for the mammal, the kangaroo rat. Once such effects are known and recognised whenever colonies of spadefoot toads or similarly sensitive animals are being assessed, then there should be no problem. However, it is important to recognise that significant adverse impacts can arise in some animals whenever some characteristic of the noise exposure interferes with an animal's behaviour. Therefore, if an animal's full behavioural repertoire and the noise source characteristics are not fully understood, it should not automatically be assumed that an adverse effect is not possible.

5.4 Reptiles

The responses reported for reptiles do not suggest a particular sensitivity to noise, although evidence of TTS was reported frequently. The key effects were the ability of ORV noise to cause TTS even when the animal (lizard) was buried under shallow layers of sand, and a 'freezing' response in the desert tortoise, which could leave the animal vulnerable to predation.

5.5 Birds

Birds represent the largest class of animals studied after the mammals. The varied responses make it difficult to derive an overall threshold for likely adverse response, and some species are more or less sensitive than others. *Running birds* (ostrich, emu and rhea) appear to be particularly sensitive to aircraft noise with moderate and severe responses at distances greater than 305m. *Colonial birds* (pelicans) showed a similar tendency to panic, causing damage to nests and eggs. *Divers and loons* showed responses to boating activities, low level aircraft and humans, most particularly close to breeding/nesting sites.

Herons and storks generally showed only slight responses to aircraft and helicopter overflights, even at heights as low as 60m. In one study, helicopter exposure caused less disturbance than fixed wing aircraft, which is in contrast to most other study findings. Therefore, perhaps these species are less sensitive to noise.

Ducks, geese and swans showed two instances of a severe reaction, which were both in response to helicopter flights that caused snow geese to leave their nests for prolonged periods during which time their eggs suffered predation, and likwise flushed Tundra swans causing them to abandon nests. Moderate responses in ducks arose due to boating activities, which were found to be disturbing during staging prior to migration and after nestling. In contrast, aircraft noise tended to generate only mild responses in ducks, similar to the situation for herons and storks. Geese, predominantly Branta species, showed moderate responses to the following exposures: military jets flying below 152m; frequent aircraft overflights lower than 1,220m; fixed-wing and helicopter overflights below 304m; fixed-wing and helicopter overflights below 530m; helicopter noise; light aircraft below 304m; frequent aircraft overflights; helicopters up to 9 km distant; and float plane disturbance over 3 days. The typical responses involved panic flushing with birds leaving the area entirely or for prolonged periods, and resulting in smaller flock sizes after regrouping.

Therefore, so far as waterfowl are concerned, geese species appear to be the most sensitive, and noise from fixed-wing aircraft and helicopters tends to cause the worst responses. It seems that isolated aircraft and helicopter overflights are more likely to cause adverse responses when they are closer to the birds, e.g. less than approximately 304m, and that as the frequency of overflights increases so the zone of influence will increase to approximately 1,220m or more. Sources having complex noise signals, e.g. helicopters, or capable of causing more direct impacts upon the habitat, e.g. float planes and boats are more likely to cause effects in isolation or over greater distances.

Some *birds of prey* (peregrine falcon and gyrfalcon) exhibited severe responses to helicopters below 610m and aircraft overflights in general, which caused some nests to be abandoned. Moderate responses occurred for condor, when noise from blasting, drilling, sonic booms and low altitude aircraft caused nest abandonment; for eagles and falcons due to the sudden appearance of helicopters; and for osprey due to the presence of motor boats. Unfortunately, as with the response of ducks to noise from boating activities, there is no recorded information on the type of boats, their speeds and proximity. It is evident that the greatest response to noise often arises due to the sudden appearance of a noisy source, as demonstrated by the response of the eagles and falcons to the sudden appearance of helicopters over a cliff top compared to either visible approaches or flights at a constant and exposed distance to the birds. With some high speed motorboats it is possible that their sudden appearance around headlands might have similar 'shock' effects. Also, for those boats whose speeds cause them to occasionally ride above the water, their changing noise levels and tonal characteristics as propellers leave and re-enter the water may generate confusing signals similar to helicopters that do not enable animals to clearly identify the speed of approach and hence the degree of threat.

One interesting point for birds of prey is that of the 35 studies referenced, 9 of these (nearly 26%) recorded no effect at all in response to noise exposure to light aircraft, artillery noise, jet aircraft, helicopters and lorries, which implies a certain degree of resilience against noise. One might expect that predatory animals, and also carrions, would be less sensitive to situations that might suggest danger, e.g. with higher noise levels, because they themselves are not normally prey to other species, and an 'adventurous spirit' has to be an inherent part of a predatory lifestyle.

The difficulty in defining problematic sources is demonstrated by responses for eagles where in one case they exhibited greater responses to small jets than other aircraft, yet in another case jet engines caused less response than piston engine aircraft. Another anomaly appears to be the fact that they exhibited far less response to artillery noise than small bore gunshots, although it is possible that this is because the latter is associated with the presence of humans at much closer locations than normally associated with artillery noise. For osprey, motorboats were again a significant cause of adverse responses.

If one looks at the noise levels recorded for birds of prey, then L_{Amax} levels of 52-101 dB due to low-level jet aircraft and 80-87 dB due to aircraft bombs had no effect on osprey and harrier respectively. Slight responses resulted for peregrine falcon at levels of 85 dB(A) due to jet overflights; for red-tailed hawks at levels of 78-89 dB(A) due to low jet overflights; and for peregrine falcons and other raptors at levels of 82-114 dB(A) due to low-level jets and sonic booms. It is not readily apparent at what noise level adverse responses, i.e. moderate or worse, are likely to be found. However, it has been established that natural noises, such as rain, wind and thunder will often generate levels in excess of 80 dB(A). The majority of the above noise levels are greater than 80 dB and yet do not give rise to harmful effects, therefore, **a level of 80 dB L_{Amax} may be a reasonable marker below which harmful or significant impacts are not considered likely**. This threshold will be tested against the literature for other species in the following sections.

Another useful means of denoting a threshold is in terms of distance from the source. Even at distances of 15-60m light fixed-wing aircraft did not cause more than slight responses from eagles. The category 'aircraft', which unfortunately can encompass all types of flying vehicles, produced slight effects at distances between 20-600m. Helicopters likewise produced slight responses at distances varying between 30-800m, although in one instance a severe response occurred for peregrine falcons at distances less than 610m. Therefore, on the whole, aircraft overflights of any type tend not to cause harmful responses in birds of prey, although the possibility of adverse responses cannot be ruled out. Adverse responses were noted when helicopters made sudden appearances over cliff tops rather than parallel flights at distances of 800m. A threshold value is not obvious from this information, although various limits have been applied ranging from the exclusion of aircraft within 1,100m of nest sites, the exclusion of aircraft within 625m of foraging habitats and the exclusion of aircraft within 150m of breeding habitats. **No significant responses are noted for distances beyond 1,000m, therefore, this may be another reasonable marker beyond which harmful or significant impacts are not considered likely.**

Of the group comprising *fowls, turkey and pheasant* etc., chickens showed a moderate response to 3 or more days exposure to aircraft noise, but this would be an unnatural level of exposure. If one looks at the noise levels recorded for this group of birds, then levels of 74-82 dB due to sonic booms, 80-115 dB due to aircraft flyovers, 96 dB due to aircraft flyovers, and 110-135 dB due to low-level jet aircraft had no effect on quail, chicken, chicken and turkey respectively. Slight responses resulted for chicken at levels of 100 dB due to general noise; for wild turkey at levels of 103-111 dB(A) due to sonic booms; for chicken at levels of 115 dB due to aircraft flyovers; and again for chicken at levels of 156 dB due to sonic booms. **The slight responses all occur at levels greater than 80 dB and greater than levels commonly associated with natural events such as meteorological factors. Therefore, a level of 80 dB L_{Amax} may again be a reasonable marker below which harmful or significant impacts are unlikely.**

In the case of source distances, slight responses occurred for jet aircraft at distances below 914m, and for sonic booms at distances between 91-750m. **Once again, the data suggests a distance of 1,000m might be appropriate as a threshold within which assessment should be undertaken.**

Only a few studies relate to *cranes and rails*, however, the proximity of the noise sources – 4m from highway traffic and 40m from helicopter flyovers – and the slight or no responses caused, imply a degree of insensitivity to noise. Highway traffic will invariably generate noise levels above 75 dB at 4m from major roads, and helicopters certainly generate noise levels above 80 dB at 40m. **Therefore, a threshold of 80 dB for the requirement of an assessment would not be inconsistent with the reported findings for this animal group.**

The group of *waders and gulls* shows one severe and one moderate response, which suggests a certain sensitivity to noise. However, of the recorded noise levels, levels of 68-93 dB due to sonic booms, and 92 dB(A) due to jet aircraft flyovers, had no effect on lapwing and herring gull respectively. Slight responses resulted for terns, most particularly at levels greater than 85 dB(A) due to noise from overflying float planes; and a moderate response occurred for herring gull at levels of 108 dB(A) due to supersonic aircraft. **A threshold level of 80 dB(A) would again fit appropriately between the no or slight responses and the onset of significant effects.**

Of the referenced distances to noise sources, these were 95-220m for sonic booms (no response), 76-305m for aircraft (slight), 100m for aircraft (slight), 800-4,800m for helicopters (no response) and 800-6,000m for helicopters (slight). Although responses to helicopters beyond 1,000m were recorded these were very slight and certainly not adverse or harmful. Supersonic transport and associated sonic booms seem to cause the most adverse responses for this group of birds.

A useful measure is provided by the referenced colony noise level for herring gull, which, including distant traffic noise, is a level of 77 dB(A). It demonstrates that large colonies of birds, and indeed other animals that vocalise within large social groups, themselves generate high noise levels that may often equal or exceed some environmental and man-made noises. The data for bird dawn choruses presented in Chapter 4 showed L_{Aeq} levels of 65-70 dB in the vicinity of the birds, with L_{Amax} levels reaching 86 dB. These noise levels present a strong indication that levels at the birds themselves will be higher and often above 80 dB. **Therefore, a threshold value of 80 dB would fit comfortably alongside these exposure levels.**

There is only limited data relating to *pigeons and doves*, *parrots and parakeets*, *owls*, and *woodpeckers*, which does not enable useful conclusions to be drawn. However, it is important to note that levels as low as 46 dB $L_{Aeq\ (10\ seconds)}$ due to chain saws were able to cause flushing of a species of owl during the nesting season. During the non-nesting period the sensitivity to noise decreased and the flushing threshold increased by 5 dB to 51 dB L_{Aeq}. This is much lower than the proposed threshold of 80 dB for assessment purposes and illustrates the problems associated with defining an absolute value when its rigid application might lead to potential adverse responses being disregarded. In the case of the owl and the chain saw, the response was only categorised as slight and, therefore, **does not dismiss outright the use of 80 dB as a threshold** below which, in the majority of cases, no long-term or harmful responses will arise. In any event, the influence of the human operator of the chainsaw is not taken into account and many studies report greater response to humans than the actual noise level.

The *perching birds* showed two moderate responses to environmental noises - for Lapland longspur exposed to low-level (15m) helicopters and aircraft. Other responses were predominantly slight. Recorded noise levels ranged from 50 dB (birdsong) up to 138 dB due to sonic booms. It is interesting that for chiffchaffs, when birdsongs reached a level of 75 dB the heart rate of the listening bird was altered. **This level, which represents a natural level regularly experienced, is not too different to the proposed threshold of 80 dB, and the reaction would represent the onset of physiological responses that are not harmful.** Responses in relation to road traffic and railway noise do not, however, fit neatly with the proposed threshold. Decreases in breeding density were observed at traffic noise levels above 50 dB $L_{Aeq\ (24\ hour)}$ and out to distances of up to 500m in different woodland densities, and for railway noise at levels between 42-49 dB $L_{Aeq\ (24\ hour)}$. The responses were, nevertheless, analysed here as slight since they did not cause harmful responses and only lead to a small relocation within the local home habitat, which allowed a return to pre-exposure conditions relatively quickly and without continuing effects. **The 80 dB threshold would on this basis suit the onset of significant responses where there is a greater likelihood of moderate or severe responses, with the possibility of slight responses below 80 dB.**

The source distance data for perching birds does not provide a lot of supporting information for a threshold value since only two moderate responses were determined for fixed-wing aircraft and helicopters at 15m, and a slight response for jet aircraft at 6,000 to 12,500m. However, **it is consistent with the emerging threshold range of 1,000m** below which moderate/severe responses may be expected in birds and beyond which there will be slight or no responses.

5.6 Mammals

Although the documented responses for mammals cover the majority of different species within this Class, there are often insufficient numbers within Orders and Sub-Orders for individual species to be analysed by different groupings. Therefore, mammalian responses have been analysed as a single group using those responses that were classified as moderate or severe. Noise levels and distance thresholds associated with the moderate and severe responses are listed in Table 5.8, excluding for now marine mammals where the exposure circumstances will be different.

Table 5.8: Noise level and distance thresholds that have been determined from the literature review to produce moderate and severe responses in mammals

Noise Level		Distance	
dB	**Source**	**m**	**Source**
65-105	Sonic boom	30	Helicopter
128	General	305	Fixed wing
130	Sonic boom	31	Fixed wing
160-168	Sonic boom	31	Helicopter
95	ORV	61	Fixed wing/helicopter
N/A	Sonic boom	152	Fixed wing/helicopter
105	Subway	241	Fixed wing/helicopter
127	Jet	30	Helicopter
106	General	61-149	Fixed wing
105	General	49-198	Helicopter
92	General	300-430	Helicopter
NA	Seismic activity	N/A	Helicopter
NA	Petroleum exploration	N/A	Aircraft
NA	Sonic boom	'Low'	Jet
75 and 100	General		
Range: 65-168 dB		Range: 30-430 m	

Apart from the reported noise levels of 65 and 75 dB, all the others exceed the postulated threshold of 80 dB. The reported level of 65 dB related to laboratory noise exposure causing hearing loss in chinchilla, and the moderate response (cochlea cell damage) should have been associated more with the noise levels at the upper end of the range, i.e. 105 dB. Similarly the reported level of 75 dB, which related to the moderate response of sheep eating less, should again be associated most with exposures at the higher noise level, i.e. 100 dB. Overall, therefore, **the main adverse responses for mammals still tend to fit the hypothesis that adverse moderate and severe responses only occur above 80 dB and 'no' or 'slight' responses below this level. Likewise, the moderate responses relative to the source distance all occurred below 1,000m for exposure to fixed wing aircraft and helicopters.**

A distance threshold of 1,000m derived from the above analysis of bird and mammalian responses is consistent with studies that indicate that startle effects arising from low-flying jet aircraft commence when the aircraft altitude drops below 950m, and that the lateral extent of startle increases with decreasing altitudes below 950m[372].

The postulated threshold of 80 dB has been derived from the analysis of studies reviewed in this thesis, and it is supported by the personal observations described in Chapter 3 relating to the responses of wild rabbits, dairy cattle and alpacas to exposures of 70-80 dB(A). (Personal observations during the measurement of outdoor PA noise similarly indicated that feeding wild deer were not affected by L_{Amax} of up to 80 dB but they immediately bolted when they became aware of my presence.) The derived level also finds support in other literature, for example, one recognised source[19] states that in the case of acoustic startle responses in laboratory animals "impulses at frequencies within the range of best hearing with onset rates better than around 20 dB/sec, and levels exceeding around 80 dB, trigger the reflex. At frequencies below 100 Hz, the response is considerably reduced". The same source provides the information in Table 5.9 for various familiar sounds in air and water. Although the information in the table is generalised, it indicates that for animals affected by sounds in air **the threshold for the shift from safe to harmful noise will lie somewhere between 70 to 100 dB. The average of 85 dB is again comparable to the 80 dB level postulated here for assessment purposes.**

Table 5.9: Sound pressure levels relative to animal responses[19]

In air		Equivalent	In water	
Example source	**SPL dB**	**Intensity (watts/m²)**	**SPL dB**	**Example source**
Sound just audible to nocturnal carnivore	-20	1×10^{-14}	42	Sound just audible to bottlenose dolphin
Sound just audible to humans	0	9.5×10^{-13}	61	Quiet ambient in small bodies of water
Quiet desert	20	9.5×10^{-11}	81	Ocean ambient, no wind
Night-time, home	40	9.5×10^{-9}	101	Sound just audible to salmonids, tuna
Normal speech	60	9.5×10^{-7}	121	50% of mysticetes respond to human-made noise
Safe limit continuous noise	70	9.5×10^{-6}	131	
	90	9.5×10^{-4}	151	Safe limit for smallfish (20-30 min exposures)
Startle reflex stops habituating	100	9.5×10^{-3}	161	Noise made by vessels
Threshold of auditory pain in humans	120	9.5×10^{-1}	181	Sounds causing discomfort in seals, divers
Jet aircraft at 50m	130	9.5	191	Maximum level of whale calls
Rocket noise at 500m	160	9.5×10^{3}	221	Intense engine noise underwater
One-quarter stick of dynamite at 1m	180	9.5×10^{5}	241	
	200	9.5×10^{7}	261	Intense seismic survey impulses

The equivalent intensity presented in the middle column of Table 5.9 enables the SPL to be calculated for the respective media using the relevant equations in Table 5.10.

Table 5.10: Sound Pressure Level Calculations

Air	Water
$p^2 = I \times \rho \times c$	
Where: p = pressure, Pa I = intensity, watts/m^2 ρ = density of air, 1.2 Kg/m^3 c = velocity of sound in air, 343 m/s	Where: p = pressure, Pa I = intensity, watts/m^2 ρ = density of water, 974 Kg/m^3 c = velocity of sound in water, 1510 m/s
$SPL = 20 \times \log_{10}(p/p_o)$	
Where: p = pressure, Pa p_0 = reference pressure in air, 2×10^{-5} Pa	Where: p = pressure, Pa p_0 = reference pressure in water, 1×10^{-6} Pa

If one uses the steps in Table 5.10 to calculate the intensity of an SPL threshold of 80 dB in air, and from this the equivalent SPL in water, the results are as follows:

Air	Water
SPL = 80 dB $SPL = 20 \times \log_{10}(p/p_o)$ $p = 10^{(SPL/20)} \times p_o$ $p = 10^{(80/20)} \times 2 \times 10^{-5}$ p = 0.2 Pa	
$I = p^2/(\rho \times c)$ $I = 0.2^2/(1.2 \times 343)$ $I = 9.718 \times 10^{-5}$ watts/m^2	$p = \sqrt{(I \times \rho \times c)}$ $p = \sqrt{(9.718 \times 10^{-5} \times 974 \times 1510)}$ p = 11.955 Pa
	$SPL = 20 \times \log_{10}(p/p_o)$ $SPL = 20 \times \log_{10}(11.955/1 \times 10^{-6})$ SPL = 141.6 dB

An exposure level of 80 dB in air is, therefore, equivalent to a received level (RL) of approximately 142 dB in water, which is consistent with the RL for fish and marine mammals of 140 dB re: 1μPa rms (see Appendix IV and section 5.2). Therefore, the proposed thresholds for assessment of noise effects in air and water environments operate from the same sound intensity.

With regard to the derivation of a noise threshold, a large number of the referenced noise levels for all animal species were identified as A-weighted values, therefore, for assessment purposes an A-weighted threshold value would seem most appropriate for use in the assessment procedure. Most noise surveys undertaken for environmental assessment studies also tend to use the A-weighting, principally because of the need to assess the impact of developments on humans. The audiogram data presented in Chapter 2 supports this approach since, for frequencies up to 4,000 Hz, the human threshold is representative of the lowest noises likely to be audible to mammals, and the majority of the threshold curves lie above that for man, i.e. most require a higher noise level before being audible. Many mammals have much better high frequency hearing than man, with ranges extending to between 40,000 to 100,000 Hz, but these are not the frequencies altered by the A-weighting corrections. The minimum threshold audiogram curves similarly show that birds, amphibia, reptiles and marine mammals (in air) tend to have threshold curves above that for man at the lower frequencies.

However, an animal's particular hearing sensitivity may mean that unweighted noise levels may be more relevant in some circumstances. For this reason, it would be helpful to understand the typical differences between A-weighted and linear levels for different types of noise source likely to be encountered in the environment, so that judgement can be made as to the likely significance for different animals and whether the assessment threshold should be A-weighted or linear. To investigate this point I have monitored noise levels in the vicinity of various noise sources using the following equipment:

CEL-90249	eNVi system hardware with NoiseMaster and FrequencyMaster software;
CRL MV 181A	Pre-amplifier and cable;
MK 224	Precision ½ inch electret condenser microphone + windshield;

Fujitsu Siemens B Series Lifebook laptop computer;

Sony TCD-D10 ProII Digital Audio Tape Recorder;

USB-One High Performance Audio Interface; and

Larson Davies CA200 acoustic calibrator.

Linear and A-weighted third octave band frequency data for each of the noise sources is presented in Appendix VII and the information enables the difference between the overall dBLin and dB(A) alternatives to be quantified. The results are summarised in Table 5.11.

Table 5.11: Comparison of linear and A-weighted noise levels measured by Author for various noise sources

Source		Sample										
		1	2	3	4	5	6	7	8	9	10	Average
PE4 explosive (at 100m)	dBLin	92.5	92.4	93.0								
	dB(A)	80.7	78.4	73.8								
	Difference	11.8	14.0	19.2								**15.0**
Fireworks (at 2,300m)	dBLin	81.4	87.0	78.2	69.3	63.6	79.0	66.9				
	dB(A)	71.7	67.7	65.1	59.8	56.0	69.6	55.2				
	Difference	9.7	19.3	13.1	9.5	7.6	9.4	11.7				**11.5**
Low-flying jet (at <1,000m)	dBLin	93.1	93.0	92.4	92.0	91.2	94.0	92.2	93.4	92.1	93.1	
	dB(A)	86.7	86.4	82.2	83.3	86.7	90.5	86.1	86.3	87.1	88.4	
	Difference	6.4	6.6	10.2	8.7	4.5	3.5	6.1	7.1	5.0	4.7	**6.3**
Military helicopter (at 130m)	dBLin	88.5	83.3	85.3	87.7	82.7	81.0	85.2	85.9	83.3	86.7	
	dB(A)	73.4	60.7	67.1	65.3	62.9	64.0	63.9	61.7	59.1	62.9	
	Difference	15.1	22.6	18.2	22.4	19.8	17.0	21.3	24.2	24.2	23.8	**20.9**
PA/crowd noise (at 100m)	dBLin	85.8	81.9	84.7	80.3							
	dB(A)	85.6	81.8	84.4	78.9							
	Difference	0.2	0.1	0.3	1.4							**0.5**
PA/crowd noise (at 400m)	dBLin	72.1	72.2	72.7	72.0							
	dB(A)	70.6	71.4	70.9	69.4							
	Difference	1.5	0.8	1.8	2.6							**1.7**
Road traffic (at 10m)	dBLin	75.1	79.7	76.6	77.9	78.2	79.4	77.5	73.9			
	dB(A)	66.8	68.0	68.4	67.7	70.1	71.1	69.1	68.0			
	Difference	8.3	11.7	8.2	10.2	8.1	8.3	8.4	5.9			**8.6**
Railway (at 20m)	dBLin	86.8	86.1	70.2	80.0	80.9	78.1					
	dB(A)	86.1	84.2	64.2	78.1	78.1	74.7					
	Difference	0.7	1.9	6.0	1.9	2.8	3.4					**2.8**
Birdsong (at <10m)	dBLin	68.7	58.8	60.5	59.0	60.2						
	dB(A)	68.3	58.6	60.0	57.3	59.4						
	Difference	0.4	0.2	0.5	1.7	0.8						**0.7**
Background (rural)	dBLin	69.7	73.5	66.4								
	dB(A)	49.6	51.8	46.3								
	Difference	20.1	21.7	20.1								**20.6**
Background (urban)	dBLin	Day:	68.0	68.4	Night:	42.1	48.1					
	dB(A)		53.9	53.7		30.4	30.8					
	Difference		14.1	14.7		11.7	17.3					**14.5**

The most interesting aspect of the above data is that military helicopters displayed the greatest variation between dB(A) and dBLin values with an average of 21 dB difference, which is consistent with helicopter noise tending to cause greater responses in animals. At the other end of the range, noise from birdsong had the smallest difference of 0.7 dB followed by PA/crowd noise at approximately 1 dB. These findings are consistent with the frequency content of the measured sounds in that helicopter noise is mainly low frequency and birdsong is mainly high frequency. Other sources showed the following differences in ascending order – rail noise (3 dB), low-flying jets (6 dB), road traffic (9 dB), fireworks (12 dB) and plastic explosive (15 dB). Background noise levels showed a high difference of 15 dB in urban areas increasing to 21 dB in a quieter rural location.

A noise assessment will neeed to take account of the frequency content inherent to the source (i.e. at close range) and that at an animal's position, which will differ due to the propagation filter that results in high frequency sounds attenuating faster with distance. The filter effect means that there will be more low frequency noise and hence a larger difference at greater distances from each source. This effect is illustrated by the data for PA/crowd noise, which shows a small increase in the difference between dB(A) and dBLin values between 100 and 400m. Since the frequency content of human vocalisations will reflect the auditory response and hence the A-weighting scale, the small difference for this source is to be expected. Other sources are likely to exhibit a greater low frequency content and hence increasing differences between dB(A) and dBLin values with increasing distance from the source.

The data in Appendix VII and Table 5.11 enables further comparison of the implications of having an assessment threshold set as either dBLin or dB(A) values.

For each source, a threshold level of 80 as either a dBLin or dB(A) value has been converted to the equivalent alternative dB(A) or dBLin values using the average differences derived from the data in Table 5.11 and the results are presented in Table 5.12.

Table 5.12: Implications of linear or A-weighted units for an assessment threshold of 80 dB

Source	dB(A) relative to 80 dBLin threshold	Threshold	dBLin relative to 80 dB(A) threshold
PE4 explosive	65	80	95
Fireworks	68	80	92
Low-flying jets	74	80	86
Military helicopter	59	80	101
PA/crowd noise	79	80	81
Road traffic	71	80	89
Railway	77	80	83
Background	63	80	97

In the case of an 80 dBLin threshold, A-weighted environmental noise levels are likely to range from approximately 60 to 80 dB(A). Since many natural sources of noise cause noise levels within this range and higher at animal positions, to set the assessment threshold this low would lead to little distinction between different situations when the purpose of the assessment method is to sort out those that may cause permanent or harmful responses from those that have slight or no effects. A threshold of 80 dB(A) provides the level of distinction required yet, based on the analysis of animal responses, it, together with the 1,000m distance threshold, also offers a safety net approach by ensuring that all moderate responses will be captured by these thresholds. For an 80 dB(A) threshold, dBLin values of environmental noises will be higher and are likely to range from approximately 80 to 100 dB, however, stages 7 and 9 of the proposed assessment methodology that follows require appropriate consideration of the frequency components of both the noise source and the animal's hearing, which will take account of the potential effect of the difference between dB(A) and dBLin exposures.

In the assessment methodology that follows, I initially considered a threshold of 80 dB as either an L_{Amax} or L_{Aeq} value, however, a level of 80 dB L_{Aeq} will automatically include events of 80 dB L_{Amax} or more, therefore, the threshold value can be refined to a level of just 80 dB L_{Amax}. Factors such as the number and frequency of events above 80 dB L_{Amax}, which will determine the L_{Aeq} noise exposure, are matters that will again be covered by sections of the assessment methodology.

The risk for marine mammals is different in that underwater sources represent the greatest likely source of noise exposure. The recorded data indicates that a Received Level of <120 dB re: 1μPa rms has no risk of non-injurious harassment. A level of 140 dB re: 1μPa rms has been used as an exposure limit for studies such as ATOC and SURTASS. On the evidence available, if effects arise between 120-140 dB these are only likely to be slight, therefore, a RL of 140 dB re: 1μPa rms is realistic for a threshold for assessment of noise effects on marine mammals.

5.7 Assessment Procedure

This section uses the information derived from the above analyses of animal responses to develop a recommended approach to the assessment of noise impacts on animal communities. Circumstances when an assessment should always be undertaken are established, and a screening procedure is developed for other situations. The stages to be considered during an assessment are defined, and the process results in the assignment of a level of significance, which determines whether mitigation measures are required. The various steps I have formulated for this process are as follows:

1. An assessment should always be undertaken when the proposed development or the study area include one or more of the following:

   i) off-road vehicles (ORV), e.g. trail bikes, dune buggies etc. (ORV tend to have less screening of engines or less effective exhaust systems);

   ii) very quiet habitats such as desert and scrubland;

   iii) animals having special hearing characteristics relative to the frequency characteristics of the noise under consideration; and

   iv) helicopters (assessment of helicopters is recommended in all cases due to the complexity of the transmitted noise signal and the observed responses at distances greater than 1,000m.).

   In the case of any of the above circumstances proceed to step 3. (It is not practicable to identify here each and every animal that might be classified as having special hearing characteristics since this may depend not only on an animal's physical and behavioural characteristics, and its hearing sensitivity, but also the frequency characteristics of the noise source. It will be necessary for the assessors to make a professional decision based on site specific information and make an inventory of animals likely to be affected.)

2. For all other circumstances apply the following screening procedure:

   i) In the absence of noise data, if the separation between the animal and the noise source is more than 1,000m no further assessment is required. Alternatively, if the L_{Amax} noise levels at the animal's position are less than 80 dB no further assessment is required. For fish and marine mammals, if the RL is less than 140 dB re: 1μPa rms no further assessment is required. Slight responses may still arise but moderate or severe responses having significant adverse effects on local animal populations would not be expected;

ii) In the absence of noise data, if the separation between the animal and the noise source is less than 1,000m proceed to step 3. Alternatively, if the L_{Amax} noise levels are equal to or greater than 80 dB proceed to step 3. For fish and marine mammals, if the RL is greater than 140 dB re: 1μPa rms proceed to step 3;

iii) for situations comprising unusual circumstances or where reference data may not be available, consideration should be given to proceeding to step 3. Circumstances most likely to affect animal responses are those involving the sudden and rapid onset of noise, and sources identified as important are helicopters (already covered by step 1), sonic booms, low flying aircraft, artillery/rockets, blasting/explosions, motorboats and float planes, and in the case of fish intense underwater impulse noise from piling or seismic activity.

3. Identify the presence of any noise-sensitive animal species that could potentially be affected by noise emissions from the proposed development. If necessary, contact relevant bodies such as English Nature and local natural history societies, or, in the case of birds, the British Trust for Ornithology or the Royal Society for the Protection of Birds, for guidance as appropriate. In the absence

of noise-sensitive animals, no further assessment would be required, otherwise proceed through steps 4 to 10.

4. Establish the species' population base within the study area, elsewhere locally and elsewhere within the region/country. This will assist with the evaluation of the importance of that species to the region and nation's population base. Contact relevant bodies for guidance as appropriate.

5. Establish whether any species have protected status via legislation or have particular relevance locally.

6. Establish the existing noise climate presently experienced by the species in the study area.

7. Establish the noise characteristics associated with the proposed development. This will need to complement the factors considered in point 9 and should include the following:

   i) identification of the absolute noise levels likely to be caused by the development, and the changes likely to be caused to ambient L_{90}, L_{eq}, L_{max} or other relevant noise units. The noise levels will need to be quantified using the weighting most appropriate to the hearing sensitivity of the animal species;

   ii) identification of the frequency characteristics of the noise, e.g. in terms of octave or third octave band noise levels; and

   iii) identify any diurnal or seasonal variations to the noise that might interact with the factors identified in point 9;

8. Define the study area in terms of the transmission characteristics of the noise, the ambient noise levels and the distribution of the animal species.

9. Establish the hearing sensitivity of the species and whether there are any behavioural traits that are strongly influenced by noise. Factors that will need to be considered will include:

   - existing use of sounds for communication, defence or predation;
   - habitat characteristics that can affect noise transmission and the noise level at the animal's sense of hearing;
   - diurnal or seasonal rhythms that might affect noise exposure, e.g. feeding and mating cycles, periods of communication, migratory patterns etc.;
   - species fecundity and maturation rate;
   - frequency characteristics of the sense organs;

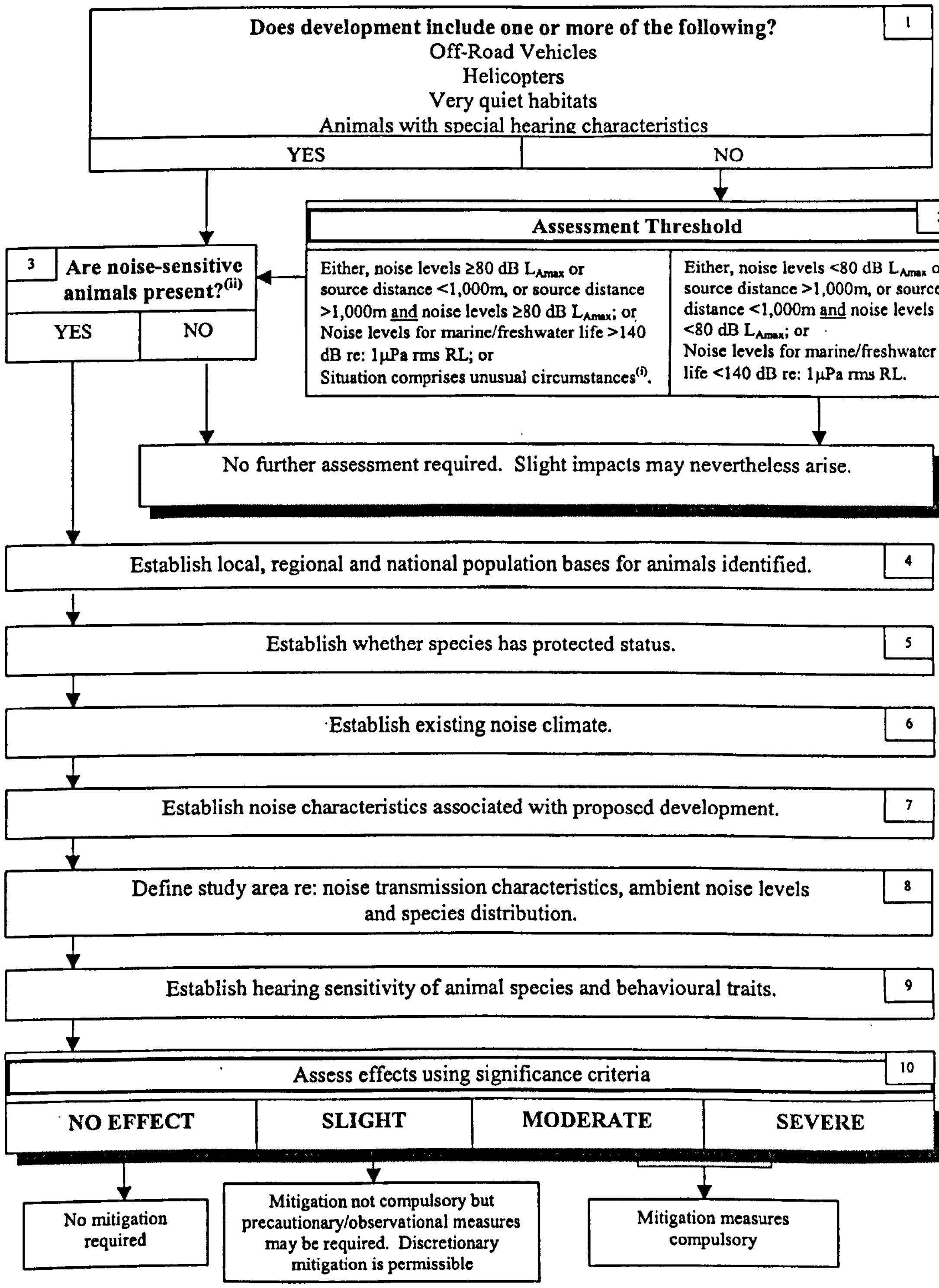
10. Analyse and assess all of the above factors and quantify the noise impacts using the significance criteria of no, slight, moderate and severe effects defined in Table 5.1. Identify the overall area of impact and formulate appropriate control measures where necessary. For responses categorised as moderate or severe, there would be a compulsory need for mitigation measures to be devised and implemented. For no effect and slight responses, mitigation measures would not normally be required. However, for slight effects where the response is not sufficiently clear cut between slight and moderate, or where there may be uncertainties whose effects cannot be defined, pre-cautionary or observational measures may be required to ensure that effects do not shift into the moderate

category, which would otherwise require definite mitigation measures. In any case where mitigation is not compulsory, mitigation would still be permissible at the discretion of the developer or jointly between the developer and the planning authority.

The above assessment stages are summarised within a flow diagram in Figure 5.1. It is important to recognise that the noise levels presented within the assessment threshold of step 2 are not intended to be used as design aims, i.e. noise levels up to the threshold are not automatically to be treated as acceptable for animal exposure. The levels relate specifically to noise circumstances within the environment and, therefore, reflect noise events that are often likely to vary with time rather than being permanent.

The assessment procedure is intended for use principally on animals most likely to be of concern during the planning process, which are mainly those Classes that provided the base information used to develop the procedures, namely land-based mammals, birds, reptiles and amphibia. However, the procedure contains appropriate thresholds for water-based species and the main assessment stages (4 to 10) are equally valid for all forms of wildlife. Stages 1 and 2 may not be applicable when some unusual species are being considered, e.g. insects. In such cases it is recommended that application of the main assessment stages (4 to 10) would ensure the matter is given due and proper consideration.

Figure 5.1: Flow Diagram for Assessment of Noise Effects on Animals



Notes: (i) Unusual circumstances will include factors such as the presence of low flying aircraft, motor boats, float planes, firing of artillery/rockets, sonic booms, explosions, fireworks, other sources causing the sudden rapid onset of noise, and for fish, intense underwater impulse noise.

(ii) Size of study area will vary according to noise source and level, and type of animals present, and may extend out to 1,000m from source, except for helicopters when effects may extend out to 5-6 km either side of flightpath.

5.8 Noise Controls

A key part of the assessment process will be the formulation of control measures that adequately minimise noise effects on sensitive animals. These, like the assessment process itself, may need to be tailored to accommodate any behavioural traits that may be specific to the animal species under consideration. For example, some birds are sensitive to noise when nesting whereas others may be imperturbable whilst on the nest but more sensitive at other times, e.g. during foraging or fledging. Therefore, care needs to be taken when formulating generalised noise controls or conditions.

The options for noise mitigation will generally comprise one or more from the following list. Due to difficulty in providing conclusive evidence on the effects of noise, a cautionary approach may often need to be taken, which may require several of the measures to be adopted. This was the situation in the case of low level flying in the Goose Bay training area[373].

- reduction of source noise levels;
- enclosure or screening of source, or screening of animal habitat;
- spatial separation - increased distance between the noise source and the sensitive area;
- application of noise limits;
- temporal separation - restrictions on hours of operation to segregate noisy events from sensitive diurnal or seasonal periods;
- real-time monitoring studies to gather population densities and locations for animals of concern, before and after exposure to noise source;
- sensitive areas restricted for specific periods of sensitivity;

- preparation of constraints maps to show sensitive areas to be protected;
- preparation of a noise management plan;
- operation of a compliance program to check that noise controls/mitigation measures are adhered to - will require participation by all relevant parties, e.g. plant operators, military, aircrews etc.;
- use of Geographic Information System (GIS) so that sensitive areas can be coded and excluded from flight plans;
- appointment of a conservation officer;
- setting up an Environmental Steering Group; and
- relocation of affected species to unaffected habitats - the latter may need to be specifically prepared/constructed to suit the needs of the relocated animal.

5.9 Summary

This chapter has developed an assessment process specific to animals, which enables informed judgement as to the likely short or long-term impacts from exposure to noise. Published animal responses have been analysed to identify particular trends and response thresholds, and a standard procedure for assessing noise effects on animals has been developed. The procedure assigns significance criteria (no effect, slight, moderate and severe) that take account of the physiological and behavioural responses exhibited following exposure to noise. The significance rating determines whether mitigation is required.

6. CASE STUDIES

This chapter tests the proposed assessment procedures by firstly applying them to the circumstances relating to a recent planning application involving the Ministry of Defence's (MoD) use of the Otterburn Training Area (OTA) within the Northumberland National Park (NNP). Secondly, the procedures have been applied retrospectively to a situation where an adverse response is known to have followed exposure to noise.

6.1 OTTERBURN TRAINING AREA

The MoD's studies into the effects of the OTA proposals commenced in 1991, the Public Inquiry sat during 1997 and re-opened in 1999 following the Government's Strategic Defence Review, and the Inspector's Report and the Secretary of State's decision notice were published in 2001.

The documentation relating to this case is, therefore, extensive, and to undertake a detailed assessment of noise effects on all the sensitive animals to be found within the Park area would itself be a prodigious undertaking. Therefore, this test focuses on application of the methodology rather than an in-depth analysis of noise sources and effects, in order to demonstrate that the procedures are workable and serve a useful function. The procedures are likewise not applied to all sensitive species found in the vicinity of the firing range but to only two selected species. Others would normally be studied in the same manner as the chosen examples.

6.2 Background

Following changes to military equipment and the withdrawal of forces from Germany, the Government published their 'Options for Change' programme[374], which represented a national strategy to meet the training requirements of the British Army. As part of this strategy, the MoD submitted a Notice of Proposed Development[375] (NoPD) to the Northumberland National Park Authority (NNPA) for new developments at OTA to support training with Artillery System 90 (AS90), a self-propelled 155mm gun, and the Multiple Launch Rocket System (MLRS). A NoPD is not a 'normal' planning application but it may often be treated in the same way by both Park and Local Authorities, and when Northumberland County Council resolved to object formally to the NoPD, the Secretary of State decided to determine the matter by means of a non-statutory local inquiry.

Heavy artillery firing at OTA prior to the NoPD comprised use of the Field Howitzer 70 (FH70) firing from 5 gun spurs. The proposed changes involved the construction of infrastructure that included 46 gun spurs capable of firing AS90, of which originally 3 would be capable of firing MLRS. The aim was to provide significant flexibility in terms of programming artillery firing, including the 'scoot and shoot' capability of modern weapons systems. Figure 6.1 shows a plan of part of the OTA. The gun spurs are denoted by numbered black dots, and the blue hatched areas denote farmsteads on the range.

The flexibility, and hence uncertainty, over what weapons will be used where, and for how often and in what numbers makes it difficult to be precise over the actual absolute noise levels that are likely to arise at specific receivers. At the same time, light guns can fire from almost any location on the range since they do not require designated gun spurs. However, their usage at OTA was expected to remain relatively constant, therefore, they should not represent a form of noise change for wildlife. Nevertheless, they do represent an additional noise contribution (though lower than FH70, AS90 and MLRS) that may have some relevance when considering cumulative effects.

Figure 6.1: Location of Otterburn Training Area and artillery gunspurs relative to local population centres and wildlife areas

A further aspect of change that would affect the noise exposure of animals on or around the range is the amount of ammunition that would be fired each year, the number of days when firing would take place, and also the type of shells fired, which has more of an effect on noise levels at the impact area rather than the point of firing. Table 6.1

shows the proposed numbers of rounds to be fired and compares these to rounds fired in previous years. It is important to note a steady decrease in firing of ammunition at the range under the current operating regime, which results in a dilemma as to what represents the most appropriate baseline for assessment purposes. For example, although the noise effect due to the proposed level of firing represents a finite impact, in terms of change it would be greater relative to recent years but less significant relative to earlier years.

Table 6.1: Change in proposed ammunition usage at the Otterburn Training Area relative to baseline scenarios in 1992-1995

Ammunition	**Proposed Number**	**Change relative to:**					
		92/93		**93/94**		**94/95**	
		No.	**%**	**No.**	**%**	**No.**	**%**
155 mm	3,850	+37	+1%	+995	+35%	+2,850	+285%
M28	224	+206	+1144%	+224	NEW	+224	NEW
RRTR	459	+459	NEW	+459	NEW	+459	NEW

Compared to the firing of 155 mm shells by FH70 in 1992/93, the proposed firing of AS90 only amounts to a 1% increase in rounds fired. However, compared to the statistics for 1994/95, the proposed level of AS90 firing amounts to a much more significant 285% increase. Whether there had been any increase in species population numbers with the decrease in FH70 firing levels would be an important fact for assessment purposes but unfortunately this level of information is not available from the surveys undertaken. Other noise exposure changes relate to the use of MLRS M28 rockets and the reduced range training rocket (RRTR), which largely represent a new noise source on the range.

In terms of days/year affected by gunfire noise, the average over 7 recent years of FH70 firing was 12.3 days/year. The level of firing with AS90 and MLRS is a total of approximately 30 days/year. An important factor will clearly be whether firing interferes with particularly sensitive behavioural activities of the animal being studied.

Table 6.2 provides an analysis of the type of 155 mm ammunition to be fired. This will affect the amount of 'splash' noise from shells exploding in the impact area. As reported in Chapter 3, airburst shells are noisier than point detonating shells, whereas impact indicator rounds (IIR) and other non high explosive shells generate significantly less 'splash' noise. Once again, the main feature of the analysis is what represents the most appropriate baseline. Relative to 1992/93 there is a decrease in HE shells and an increase in non HE shells, which will reduce the noise exposure for animals in the vicinity of the impact area. However, compared to 1994/95, the proposals represent a marked increase in HE shells. Clearly, to the human population around the range, this would be perceived as a marked increase to the amount of audible gunfire and impact noise heard throughout the year. However, it is unlikely that animals are able to make the same comparisons and will respond to the noise event at the time. Therefore, if the historical highest level of exposure caused, or did not cause, adverse effects within animal populations, one would expect the same degree of effects for a similar exposure at a later date.

Table 6.2: Change to the type of 155 mm ammunition fired at the Otterburn Training Area relative to baseline scenarios in 1992-1995

Ammunition	Projected average	Change relative to:					
		92/93		93/94		94/95	
		No.	%	No.	%	No.	%
Total	3,850	+37	+1%	+995	+35%	+2,850	+285%
Carrier/IIR shells (non HE)	771	+237	+44%	+371	+93%	+631	+451%
HE (airburst)	182	-9	-5%	+39	+27%	+132	+264%
HE (point detonating)	2,897	-192	-6%	+584	+25%	+2,087	+258%

The key noise concerns relating to the potential effects of changes to the firing of heavy artillery at OTA were considered to be the following:

- impacts on local residents, e.g. farmsteads on the range and small settlements around the range;
- impacts on visitors to the area, walkers and motorists;
- impacts on wildlife, particularly nesting birds; and
- vibration effects on historic monuments on the range.

For this study, the only area of interest is the noise impacts on wildlife. However, overall, the environmental assessment of the proposal covered the full range of environmental issues, which included in addition to noise, landscape and visual effects, nature conservation, ground contamination, cultural heritage, planning, traffic, construction, and recreation. As with any environmental assessment, the effects on wildlife can take a lesser or greater role in the overall consideration of the scheme impacts subject to the local importance of the various other topics being considered. Unlike other planning matters, military proposals are often determined to have especial importance due to 'national need' or 'appropriate defence of the realm' or 'to develop a force for good in the world', and such factors may often be used by the Secretary of State (SoS) to over-ride environmental issues that could otherwise affect the implementation of the proposal.

In 1998 the Government published its Strategic Defence Review[376] (SDR) and as a consequence of possible implications for the Army's training at OTA, the inquiry was reopened to consider new material. Matters raised by the SoS for consideration at the inquiry were summarised as follows:

- The extent to which the SDR is likely to affect both the need for and the intensity of training at OTA, in particular, the extent to which new factors are introduced by:
  - i) The withdrawal of troops from Germany and/or any reductions in the size of the Territorial Army;
  - ii) The location of training facilities for additional AS90 regiments;
  - iii) The training needs of a new armoured brigade and new Apache helicopter regiments; and
  - iv) Changes to munitions as outlined in the SDR.
- The extent to which there is likely to be an impact on the OTA as a result of additional information that has emerged since the closure of the Inquiry with regard to the future use of MLRS, the M28 rocket and its potential replacement;
- The potential impact of additional military convoys on the A696 and other highways; and
- Any other matters newly arising.

Most important within the above new factors is the training for the Apache attack helicopter. Under the SDR, a new air manoeuvre brigade (16 Air Assault Brigade), based on the existing 24 Airmobile Brigade equipped with anti-tank Lynx helicopters, will operate using the Westland Apache Longbow helicopter. Given the enhanced capabilities of the Westland Apache Longbow to fly lower, faster and at night, as well as the ability to acquire and engage a variety of targets rapidly, an increase in the amount of night-time training was indicated, but with limited live firing of cannon and rockets. The Apache also operates in pairs or multiples of pairs, which would increase the noise potential, although Lynx training similarly typically involves up to 8 Helicopters operating at low level behind cover, and then rising simultaneously above cover to engage the targets. Neither helicopter would be based at OTA but would fly in from some distance away, which could have some bearing for sensitive species adjacent to flighpaths.

Other matters identified for consideration included the use of unmanned aerial reconnaissance vehicles and training with a new Light Mobile Artillery Weapon System (LIMAWS) that also fires 155mm shells. The MLRS system operates using the Phoenix unmanned aerial vehicle for target acquisition, and SDR took account that it was then entering service rather than being a new factor.

Following on from the SDR, the MoD decided to undertake a Strategic Environmental Appraisal[377] (SEA) of decisions arising from the SDR, and their findings were published in 2000. The SEA is defined by the MoD as a process for looking carefully at the potential environmental effects of policies, plans and programmes and takes account of the wider context of sustainability, which includes social and economic factors. It incorporates some of the techniques of environmental impact assessment, but also draws on methods used in sustainability and policy appraisal. Although SEA is not formally required by law, Government has encouraged the use of environmental appraisal through Town and Country planning guidelines as applied extensively to Development Plans.

The form of strategic appraisal used by the MoD for the SEA was modelled on guidance set out in Policy Appraisal and the Environment[378] and developed in discussion with interested parties such as, at that time, the Department for the Environment, Transport and Regions (DETR) and others. Statutory bodies involved in the SEA process included, for example, English Nature, English Heritage, Countryside Agency, and the Association of National Park Authorities. Non-Governmental organisations included the Royal Society for the Protection of Birds, National Farmers Union, Council for the Protection of Rural England and Council for National Parks. Some of these bodies would similarly be consulted during the proposed assessment procedures for impacts on sensitive animals. The basic steps in the SEA process are identified in Table 6.3.

Table 6.3: Basic steps in the MoD's Strategic Environmental Appraisal process

1	Confirm the scope of the SEA
2	Determine methods and approach
3	Consult relevant bodies
4	Examine environmental assets and resources
5	Review the SDR programmes and activities
6	Consider interactions between the SDR proposals and the environment
7	Screen out activities unlikely to have any significant effects
8	Undertake more detailed studies where there are potential effects
9	Examine alternatives
10	Propose mitigation and enhancement measures to avoid or reduce impacts
11	Make recommendations to decision makers
12	Prepare reports of findings
13	Review the process and audit the results

Key elements in the SEA process are the screening out of activities unlikely to have any significant effects followed by more detailed assessment where there are potential effects. The same approach has been incorporated within the procedures being tested here, with the development of various thresholds that can be used to define whether significant effects warranting further assessment will arise.

6.3 Summary of MoD Assessment for Otterburn

With respect to birds, which are the main species likely to be affected by the OTA proposals, the MoD's consultants stated that "Despite the published research, assessment of the impacts arising from military activity on bird species at OTA remains, at best, uncertain". In opposition, the Northumberland Wildlife Trust also remarked that "the effect of increased disturbance on birds is very difficult to quantify". Nevertheless, the principal conclusion of the MoD presented to the inquiry can be summarised as follows:

The Otterburn Training Area is a military training area. It is not a nature reserve. However, its use for military training over some 85 years has resulted in the conservation of habitats and species which have declined in the wider countryside as a result of agricultural improvements and afforestation. MoD fully recognises the wildlife importance of the training area and has management programmes in place to conserve and enhance the wildlife resource. The MoD also recognises that introduction of AS90 and MLRS training would result in some changes to the nature and pattern of disturbance which occurs and that this may have some adverse effects on particular species. MoD has therefore proposed an improved, integrated management structure for the land at Otterburn which, together with the appointment of a Conservation

Officer, would ensure that the requirements of nature conservation are taken fully into account in the use of the training area.

6.4 Application of Proposed Assessment Methodology

The application of the proposed assessment methodology is tested below using the steps devised in Chapter 5. The whole process is followed through for a selected animal species. To demonstrate the different conclusions and actions that can be reached for different animals, the process is repeated for a second species.

6.4.1 Case 1 – Black Grouse

Step 1 - Does development include one or more of the following - off-road vehicles, helicopters, very quiet areas or animals with special hearing characteristics?

The development does not include off-road vehicles as such, i.e. trail bikes or dune buggies etc., however, the military vehicles (AS90, MLRS and associated Warrior Observation Party Vehicle (OPV)) are all military off-road vehicles that have equivalent or more low frequency sounds generated by engine exhausts. For this reason, proceeding to step 3 would be recommended regardless of the fact that the movement of military vehicles per se was not seen as a significant variation from the existing operations at OTA.

The original OTA proposals did not specifically include reference to helicopter operations within the training regimes, although there would probably have been some joint training with Lynx helicopters from time to time. Knowledge of the Apache helicopter arose from the introduction of the new air manoeuvre brigade following the SDR. The presence of helicopters would again trigger a move to step 3 in the assessment process.

The remote location and overall size of the National Park leads to very low ambient noise levels (when military training is not present) and the area is renowned for the peace and tranquillity that walkers can experience. As with most of the National Parks, background noise levels often fall to below 30 dB L_{A90} even during the day, which means that many of the animal habitats are very quiet indeed. This factor again triggers a move to step 3. Finally, at this stage of an assessment, it may not be known whether there are animals with special hearing characteristics present on or in the vicinity of the range.

Therefore, the development proposal contains three of the four factors identified in Chapter 5 as most likely to cause adverse responses in some animals, and as a consequence no further screening of noise levels and source distances (step 2) is required.

Step 3 – Are noise-sensitive animals present?

Information from the National Park Authority, Northumberland Wildlife Trust, English Nature and the Royal Society for the Protection of Birds (RSPB) indicates that the rare or protected species of animals present at OTA are as listed in Table 6.4.

It is evident from the species listed, that there are numerous animals present on the range and the surrounding National Park that would be classified as sensitive to noise disturbance. Therefore, the assessment proceeds to step 4, which is the start of the main assessment process for each animal species under consideration. (The range also comprises a large number of working farmsteads that are often close to the gunfire, and sheep and lambs should also be considered as sensitive to noise, although the analysis of animal responses in Chapter 5 demonstrates that farm animals are on the whole less sensitive than wildlife species.)

Table 6.4: Schedule of rare and protected species present on the Otterburn Training Area

Species	*Designation*
Invertebrates	
Large heath butterfly (*Coenonympha tullia*)	1
Clouded buff moth (*Diacrisia sannio*)	1
Saxon moth (*Hyppa rectilinea*)	1
Grey scalloped bar moth (*Dyscia fagaria*)	1
Ruddy highflyer moth (*Hydriomena ruberata*)	1
Golden-rod brindle moth (*Lythomoia solidaginis*)	1
Birds	
Merlin (*Falco columbarius*)	2, 3, 4, 5, 6
Peregrine (*Falco peregrinus*)	2, 3, 4, 5, 6
Red grouse (*Lagopus lagopus*)	6, 7, 8, 9
Black grouse (*Tetrao tetrix*)	5, 6, 7, 9, 10
Grey partridge (*Perdix perdix*)	5, 6, 7, 8, 9
Golden plover (*Pluvialis apricaria*)	3, 5, 6, 11, 12
Curlew (*Numenius arquata*)	5, 6, 9, 10, 13
Hen harrier (*Circus cyaneus*)	6
Goshawk (*Accipiter gentiles*)	6
Lapwing (*Vanellus vanellus*)	14
Snipe (*Gallinago gallinago*)	14
Redshank (*Tringa totanus*)	14
Dipper (*Cinclus cinclus*)	14
Whinchat (*Saxicola rubetra*)	14
Stonechat (*Saxicola torquata*)	14
Wheatear (*Oenanthe oenanthe*)	14
Ring ouzel (*Turdus torquatus*)	14
Mammals	
Badger (*Meles meles*)	15
Red squirrel (*Sciurus vulgaris*)	5, 9, 16
Otter (*Lutra lutra*)	4, 5, 17, 18
Pine marten (*Martes martes*)	5, 19

Designation: 1. rare
2. protected under Schedule 1 of the Wildlife and Countryside Act 1981

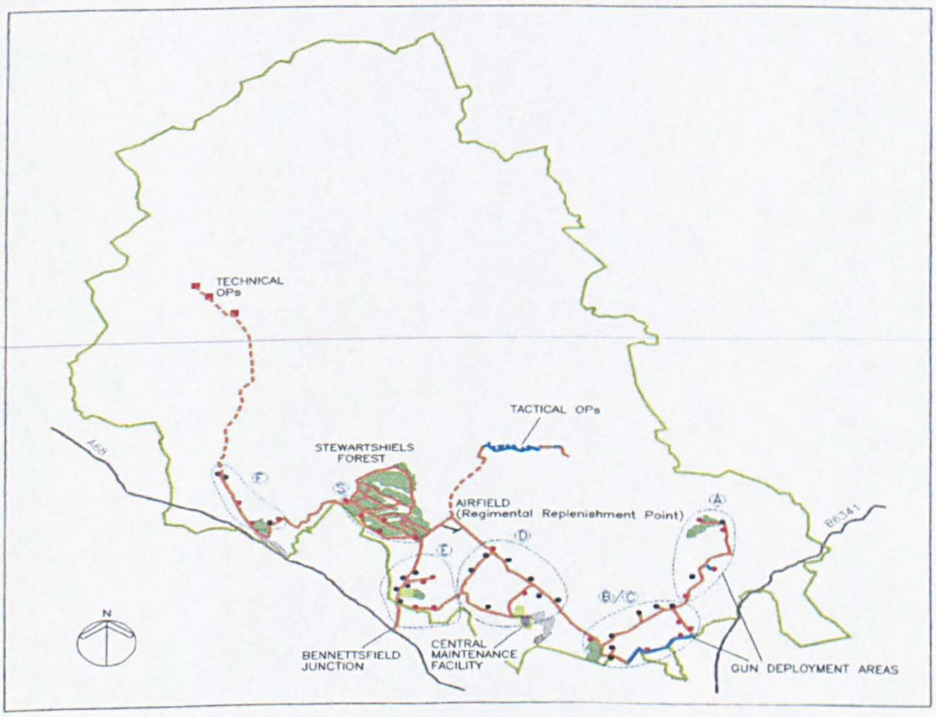
3. protected under Annex I of the Birds Directive (79/409/EEC)
4. protected under Appendix II of the Berne Convention
5. key species under the Biodiversity Convention
6. vulnerable species in the British Red Data Book
7. protected under the Game Acts
8. protected under Annex III/1 of the Birds Directive (79/409/EEC)
9. protected under Appendix III of the Berne Convention
10. protected under Annex II/2 of the Birds Directive (79/409/EEC)
11. protected under Schedule 2, Part 1 of the Wildlife and Countryside Act 1981
12. protected under Appendix 10 of the Berne Convention
13. protected under the Wildlife and Countryside Act 1981
14. candidate for inclusion in Red Data Book
15. protected under the Protection of Badgers Act 1992
16. protected under Schedules 5 and 6 of the Wildlife and Countryside Act 1981
17. listed under Annexes II and III of the Habitats Directive
18. protected under Schedule 5 of the Wildlife and Countryside Act 1981
19. protected under Schedule 5(b) of the Wildlife and Countryside Act 1981

For an initial test, only one species will be used from the list. Its selection took account of the following factors. Invertebrates do not appear to show the same degree of sensitivity to environmental noises as birds and mammals, nor are they protected in the same way. In the case of birds and mammals, the analysis of responses in Chapter 5 showed a slightly greater sensitivity to noise in birds compared to mammals, with more moderate and severe responses. Also, for those mammals present on the range, badgers are protected not for specific conservation measures but against the cruel practice of badger baiting; otters are mostly affected by water pollution; and there is no conclusive evidence of the pine marten's survival at Otterburn. Therefore, the species for study has been selected from the group of birds. Identification of the species is made in the following section because much of the information considered is directly applicable to step 4.

Step 4 - Establish local, regional, and national population bases for animals identified.

The birds with the most protective designation are merlin, peregrine, red grouse, black grouse, grey partridge, golden plover and curlew, and these formed the focus of attention by the MoD's consultants at inquiry[379]. The merlin is one of the few raptors that are declining in number in Britain, largely through habitat loss, but possibly also through chemical contamination of the environment. An RSPB survey at Otterburn[380] in 1994 identified four breeding pairs within the training area in 1994 and nesting does occur in the general areas of two of the Gun Deployment Areas (GDA) Delta and Foxtrot. The locations of GDAs are shown on Figure 6.2.

Figure 6.2: Locations of OTA Gun Deployment Areas



The peregrine also suffered a significant decline during 1957-1963, largely due to the widespread use of organochlorine pesticides in the environment. However, since then numbers have increased and the UK population of approximately 900 pairs represents 25-30% of the western European breeding population, and is therefore of international importance. The RSPB survey identified two breeding pairs at Otterburn in 1994, which were claimed by the MoD to not be close to the proposed developments.

Undisturbed cliffs or crags are often used for nesting sites, which, at Otterburn, would place them away from the more open GDA sites.

Red grouse are also of international importance, and populations have been in decline since the 1930s, largely due to failures in breeding success (possibly associated with parasite infestations) and loss of moorland habitat. An important behavioural trait that would exacerbate either the loss of habitat or adverse impacts on their habitats is that the birds are sedentary and rarely move more than a few kilometres. The RSPB survey found red grouse breeding on all significant areas of heather moorland at Otterburn, which places them in the centre and south of the range and, therefore, close to the areas of firing and also in a position to be overflown by missiles, i.e. MLRS rockets. Maximum breeding densities are $18/km^2$, and lower densities are present around the proposed GDAs Bravo/Charlie, Delta and Foxtrot.

The numbers of black grouse are also declining over much of its European range, and the North Pennines and OTA support a significant proportion of the threatened English population. The bird is also sedentary and prefers a mix of vegetation types, and the loss of suitable habitat has caused fragmentation of populations. The RSPB survey located a total of 25 males and 12 females during their first site visit, and 16 males and no females during their second. This may be because the females become more secretive when breeding. In contrast, groups of males congregate for early morning displays (leks) at established locations. Although the bubbling or crooning song of the cocks is soft, the combined sound carries a long way - 400 m or more on a still day. At Otterburn, black grouse have been recorded in the vicinity of GDAs Bravo/Charlie and Foxtrot.

The grey partridge has likewise declined from about 1950, again mainly due to the use of pesticides on arable farmland that forms their natural habitat. The RSPB survey recorded 19 pairs, with some recorded in the areas of GDAs Alpha, Bravo/Charlie, Delta and Echo.

The breeding population of golden plover has also declined in the UK, mostly as a consequence of loss of suitable upland habitat. The British breeding population is estimated to be less than 10% of the western European population and as a result is not of international importance. The RSPB survey recorded 25 pairs and the majority of these were found in the south/centre of the range, which would be overflown by MLRS rockets. None of the identified breeding locations were close to GDAs.

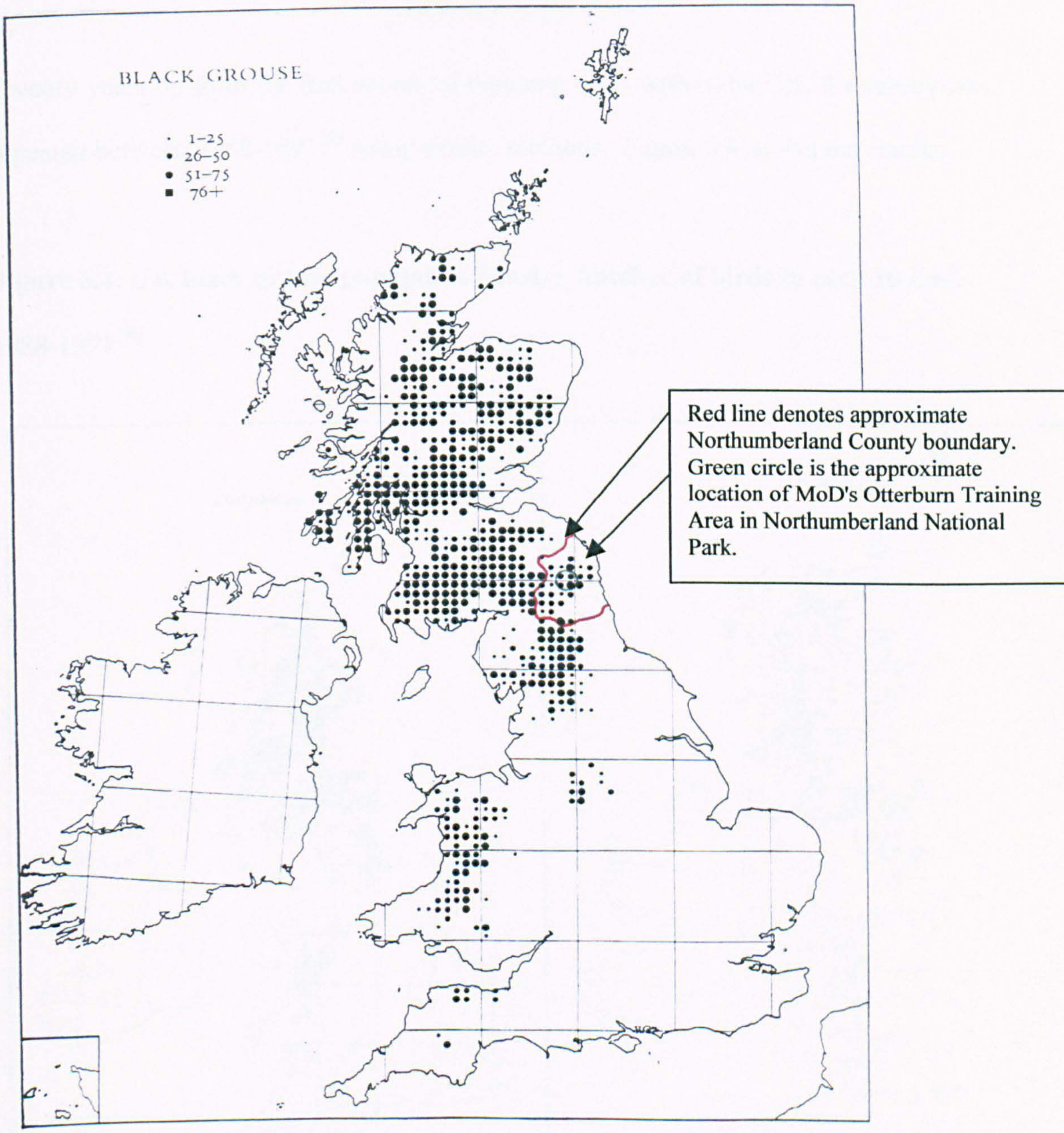
The curlew is not rare in the UK, there being a breeding population of approximately 35,000 pairs. However, the numbers amount to a significant 28% of the European total, which gives the population international significance and is the reason for the species being included in the Red Data Book. The RSPB survey recorded 486 pairs of curlew, mostly in the southern part of the range, which places the highest concentrations close to GDAs Alpha, Bravo/Charlie, Delta, Echo and Foxtrot.

Of the seven bird species discussed above, the curlew is not rare and the golden plover has not been recorded close to the GDAs, neither has the peregrine. The grey partridge is fairly widespread throughout the UK, and the red grouse also has a larger population within the UK than the black grouse. Both merlin and black grouse would be interesting birds to follow through the remaining assessment stages - merlin because of its use of the same section of moor year after year, its usual nesting behaviour within scrapes at ground level, and its hunting by means of low, dashing flights catching small birds in mid-air; characteristics that could easily be adversely affected by noise disturbance. However, the black grouse has been selected for the remaining steps in the assessment due largely to its sedentary behaviour. Many birds and other species of animals have the option to move their territorial ranges or breeding areas subject to suitable habitats being available in the neighbourhood. Flight can be used to achieve sufficient additional distance from a noise source for disturbance effects to be lessened to probably no worse than a 'slight' effect. However, since grouse do not tend to stray beyond a few kilometres from their home territory (80-90% die within 1.5 km of where they were ringed) they would be largely captive to the effects of additional gunfire noise, especially if it came closer than previously, which could exacerbate the impacts and cause more noticeable long-term effects.

In addition to the local population defined by the RSPB survey in 1994 to be possibly up to 25 pairs at Otterburn, regional and national information can be found in the British Trust for Ornithology's 'Atlas for Breeding Birds in Britain and Ireland'. From surveys undertaken between 1968-1972[381], the numbers of species found within 10-km squares across the UK were mapped and the Trust's findings for the black grouse are shown in Figure 6.3. The black dots denote the number of birds found within each 10-km square - small dots representing 1-25, medium dots 26-50 and large dots 51-75.

The surveys showed no location throughout the UK bearing more than 75 birds per 10-km square. The number of 10-km squares across the UK in which black grouse were recorded was 603 or 10% of the country. Of the 603, 47% were confirmed breeding sites, 29% were probable and 23% were possible breeding grounds.

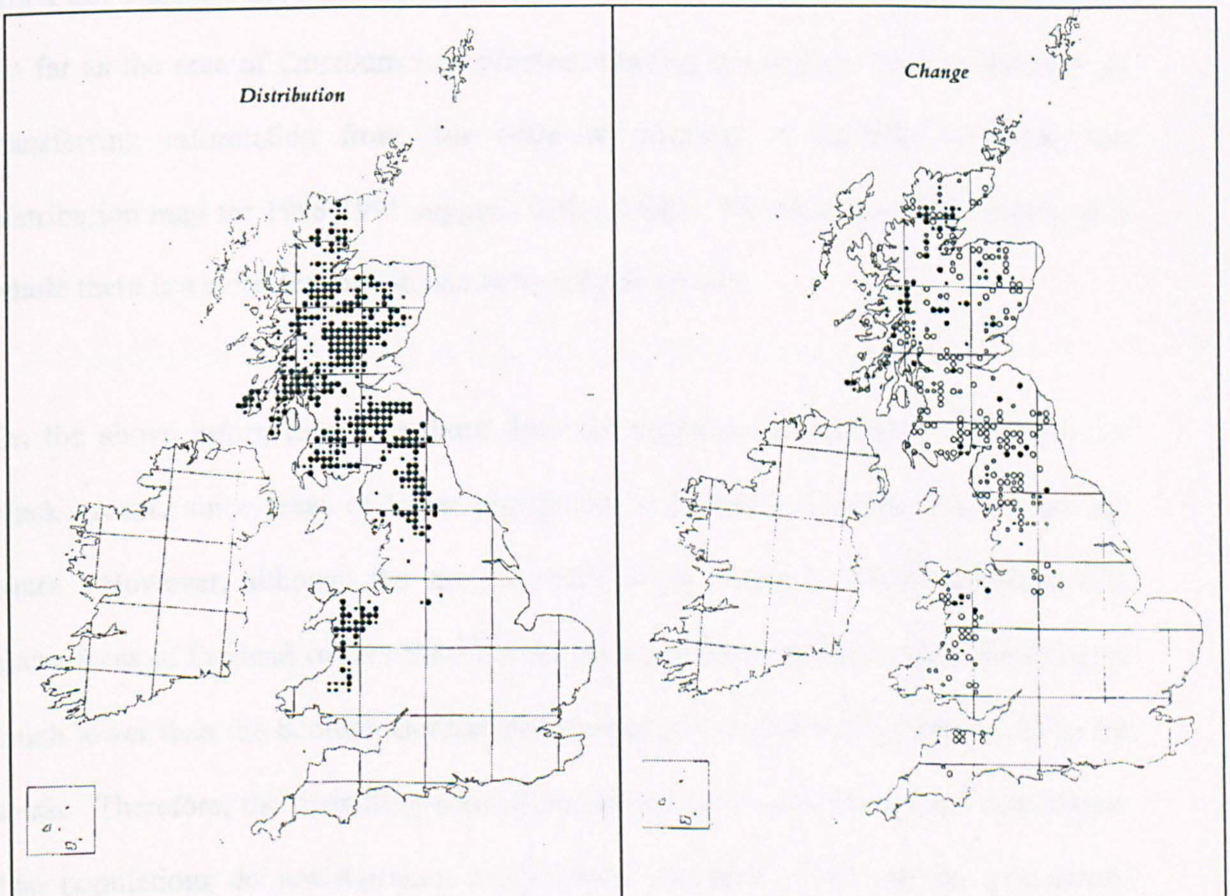
Figure 6.3: UK black grouse population density, number of birds in each 10 km^2, 1968-1972[381] (small black dot=1-25, medium dot=26-50, large dot=51-75, square=76+)



Northumberland County is identified on the UK map so that the significance of the regional population can be appreciated, and the approximate location of the OTA in the National Park is also marked. It is not possible to be precise over the exact location covered by each 10-km square relative to OTA and the National Park but the 1976 census indicates a population of between 26-50 or 51-75. The RSPB survey prior to the inquiry recorded a maximum of 37 black grouse, which is consistent with the medium size dot (26-50 birds) representing Otterburn.

Twenty years on from the first survey of breeding birds within the UK, the survey was repeated between 1988-1991[382] using similar methods. Figure 6.4 shows the results.

Figure 6.4: UK black grouse population density, number of birds in each 10 km^2, 1988-1991[382]



Distribution 1988-1991
(small black dot=1-25 birds, next dot=26-50, next=51-75, largest dot=76+)

Change from 1968-1972
(Small open dot=possible breeding in 1968-1972 but not recorded in 1988-1991; large open dot=probable or confirmed breeding in 1968-1972 but not recorded in 1988-1991; small filled dot=not recorded in 1968-1972 but present although no evidence of breeding in 1988-1991; and large filled dot=not recorded in 1968-1972 but evidence of breeding in 1988-1991.

Compared to the 603 10-km squares across the UK in which black grouse were recorded during 1968-1972, the later survey found the birds present in only 432 10-km squares, which represents an overall reduction of 28%. The decline in population numbers is, therefore, continuing. The 'Change' map in Figure 6.4 documents the recorded change in distribution between 1968-1972 and 1988-1991 using four different types of dot. The small open dot indicates possible breeding in 1968-1972 but not recorded in 1988-1991; the large open dot indicates probable or confirmed breeding in 1968-1972 but not recorded in 1988-1991; the small filled dot indicates not recorded in 1968-1972 but present although no evidence of breeding in 1988-1991; and the large filled dot indicates not recorded in 1968-1972 but evidence of breeding in 1988-1991. So far as the area of Otterburn is concerned, bearing in mind the limited accuracy in transferring information from this scale of mapping to specific localities, the distribution map for 1988-1991 suggests little change. However, over the County as a whole there is a clear decrease in numbers of black grouse.

On the above information, Otterburn does not represent the County's main area for black grouse, since areas of larger populations are identified to the north, west and south. However, although the species numbers are higher in Northumberland than many areas of England (where the birds are often no longer present), their numbers are much lower than the Scottish Borders to the west and Durham's North Pennines to the south. Therefore, the dwindling populations have both local and regional importance. The populations do not represent a significant element of the national population, nevertheless, any species having legal protection (discussed below) must also have national importance.

Outside the UK, in Holland, Belgium and much of central Europe the black grouse population has similarly declined to a low level or has become totally extinct. In southern Europe, only the Alps hold a significant population and even this is diminishing. Only in the boreal forests of Scandinavia and some of the Soviet States are populations relatively healthy and increasing in some areas.

Step 5 - Establish whether species has protected status.

The legal protection applicable to species at Otterburn has already been listed in Table 6.4. In the case of black grouse, the species is afforded the following protection:

- key species under the Biodiversity Convention;
- vulnerable species in the British Red Data Book;
- protected under the Game Acts;
- protected under Appendix III of the Berne Convention; and
- protected under Annex II/2 of the Birds Directive (79/409/EEC).

Step 6 - Establish existing noise climate

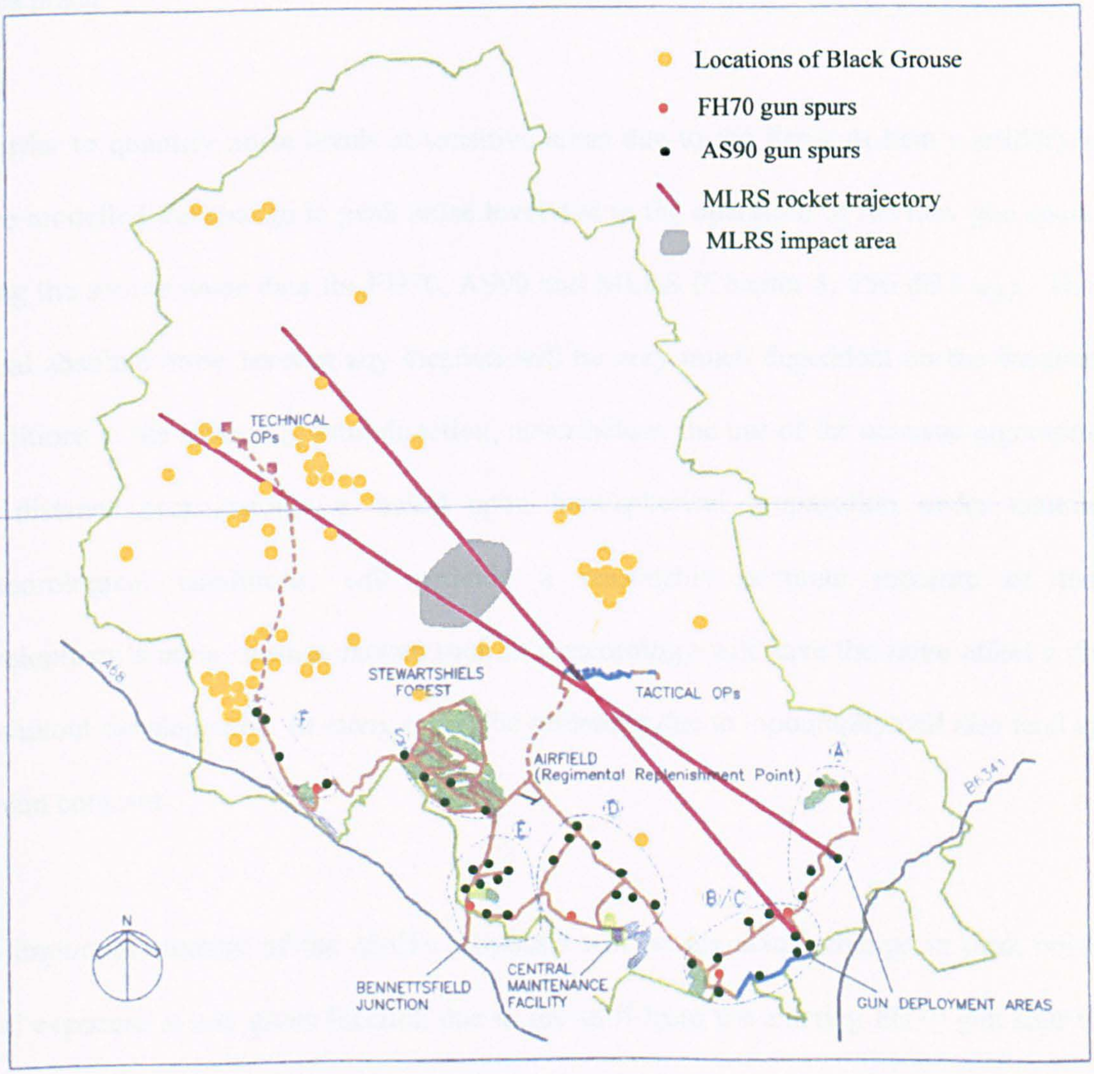
In the absence of military activities, existing ambient noise levels over the National Park are low. The areas occupied by black grouse are typically between 1-10 km from significant sources of road traffic noise, i.e. the A696 or the A68, and there are few local sources of man-made noise when the range is not in use. As a consequence, even daytime noise levels can be low, with L_{A90} and L_{Aeq} noise levels falling in the range of 30-35 dB at locations recorded as occupied by black grouse.

The most recent black grouse survey for the OTA Inquiry resulted in the bird locations shown later on Figure 6.5 (yellow dots), relative to the existing FH70 gun spurs (red dots). The yellow dots denote the presence of the blackcock or greyhen during two successive visits and do not, therefore, indicate total numbers of birds present on the range. The main locations for black grouse tend to be the lek (communal mating ground) at Wilkwood near the centre of the range, around GDA Foxtrot, and around the road leading to the Technical Outposts (OPs). In the past, black grouse have also been identified close to GDA Bravo/Charlie.

On an average of 12 days/year, the existing gun spur around the black grouse locations to the west of the range fires a total of 763 155mm shells/year, which, based on hemispherical propagation and the source noise data in Chapter 3, is calculated to produce MaxP dBLin noise levels of up to approximately 122 dB at the identified bird locations. The three existing gun spurs to the south of the range fire a total of 2,289 155 mm shells/year and produce MaxP dBLin noise levels of up to approximately 126 dB at previous black grouse locations near GDA Bravo/Charlie. Noise from light gun fire will also be present from time, as will occasional noise from Lynx helicopters and ground based support vehicles. These latter sources are likely to be common to the situation following development.

Figure 4.5 (Chapter 4) indicates that the area is subject on average to between 6 and 8 days each year when lightning will be present and as a consequence birds will be exposed at these times to varying levels of peak noise due to thunder.

Figure 6.5: Locations of OTA gun spurs, MLRS rocket trajectories, impact areas and areas occupied by black grouse



Step 7 - Establish noise characteristics associated with proposed development

The main noise characteristics associated with the proposed development will be those due to the firing of AS90 and MLRS, the passage of MLRS rockets through the air, the explosion of shells and rockets in the impact areas, and training with the Apache helicopter. The unmanned Phoenix would also be present. Noise data for these sources has already been presented in Chapter 3. The noise level and frequency content of FH70 and AS90 gunfire and splash noise are virtually identical, therefore, noise change will be a function of changing distances between existing and proposed gun spurs (see Figure 6.5), the total number of rounds fired, and the number of days/year when firing takes place.

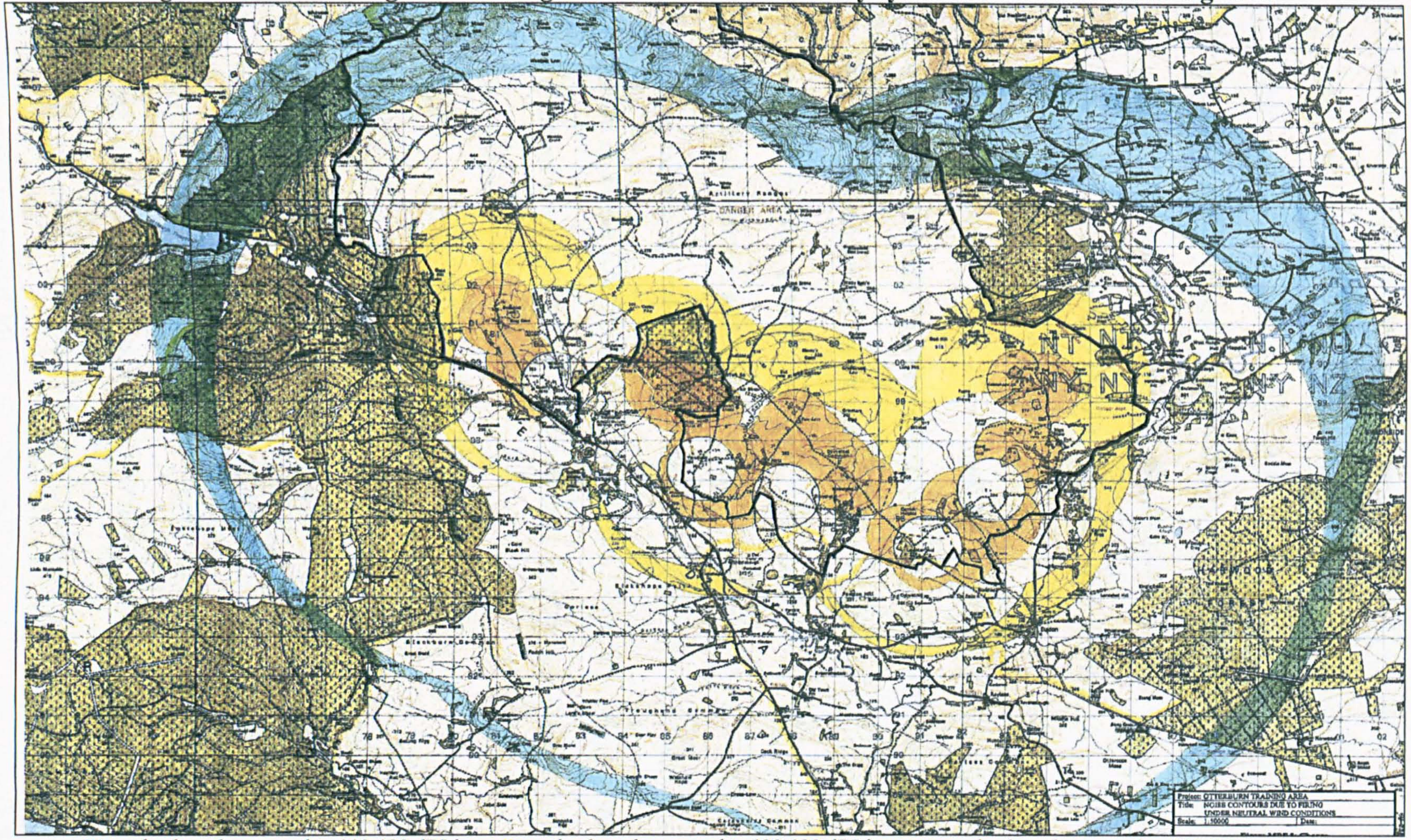
In order to quantify noise levels at sensitive areas due to the firing of heavy artillery I have modelled the change in peak noise level due to the operation of the new gun spurs using the source noise data for FH70, AS90 and MLRS (Chapter 3: 196 dB L_{WA}). The actual absolute noise level at any location will be very much dependent on the weather conditions at the time, e.g. wind direction, nevertheless, the use of the acoustic algorithm for distance propagation, i.e. based upon hemispherical propagation under neutral meteorological conditions, will provide a reasonably accurate measure of the development's impacts since factors such as meteorology will have the same effect with or without development. In many cases, the screening due to topography will also tend to remain constant.

An important element of the MoD's proposals will be the actual change in peak noise level exposure at any given location due to the shift from the existing FH70 gun spur to the nearest AS90/MLRS gun spur. The calculations have been used to derive noise contours firstly for the base situation and secondly with the proposed development. The difference between these two scenarios has been plotted to show areas newly exposed to noise levels of 110-120, 120-130 and 130 dBLin or more, which in effect shows the maximum Park area that will be subject to noise change and the degree of noise change likely to be experienced. This information is presented in Figure 6.6. The areas shaded orange denote the areas newly exposed to peak noise levels of 130 dBLin or more. The unshaded circular areas inside or immediately adjacent to the orange areas represent the sphere of influence of the existing gunspurs, i.e. where 130 dBLin is typically exceeded under the FH70 regime of firing. Likwise, the unshaded areas between the orange and the yellow represent the areas where FH70 firing presently leads to noise levels of 120-130 dBLin; the yellow area denotes land newly exposed to 120-130 dBLin due to AS90/MLRS firing; the unshaded areas between the yellow and the blue represent the areas where FH70 firing leads to noise levels of 110-120 dBLin; and the blue area denotes land newly exposed to 110-120 dBLin due to AS90/MLRS firing.

In referring to the data in Figure 6.6 it needs to be borne in mind that the noise levels are only indicative of the impacts since they do not reflect the effects of factors such as wind direction or localised screening due to terrain. Nevertheless, bearing in mind the day-to-day variations in noise exposure that will arise in any event due to factors such as weather conditions, animal mobility and different firing parameters, the information is appropriate for assessment purposes.

Figure 6.6 shows that as a consequence of the direction of fire to the northwest, and the principal movement of new gunspurs to the northwest and northeast (see Figure 6.5), land newly exposed to higher noise levels is also mainly in these same directions. The extent of change to the south is small and will amount to no more than 1-2 dB, which in environmental terms can be considered insignificant. In some cases, for example where the orange areas denoting land newly exposed to 130 dBLin or more extend to the start of or beyond the yellow areas, the noise change will be 10 dB or more. Points midway between the start of the orange and the start of the yellow will represent a change of approximately 5 dB(A).

Figure 6.6: Noise change due to firing of AS90 and MLRS artillery systems at Otterburn Training Area



Blue - land newly exposed to 110-120 dBLin; yellow - land newly exposed to 120-130 dBLin; orange – land newly exposed to 130 dBLin or more.

In addition to the peak noise effect due to firing, which will be similar for both AS90 and MLRS, MLRS will generate different tonal characteristics caused by the missile in flight and it is also capable of causing sonic boom effects at ground level. The current generation of MLRS rockets, the M28 and the RRPR, are both supersonic, having Mach speeds of 2.1 and 1.1 respectively, and travel at speeds of 714 and 377 m/s at heights above ground level of 600 and 250m respectively. On this basis, both rockets will be capable of producing sonic booms and the footprints for these are calculated to be respectively about 4 and 2 km from the rocket trajectory. The principal rocket trajectories, including the safety template beyond the impact area, are marked on Figure 6.5 and a footprint of 2-4 km either side of this would encompass the identified locations of black grouse. However, sonic booms would only be associated with the period of maximum rocket propulsion, i.e. soon after firing and up to a point shortly before the rocket impacts, which should only affect birds south of the impact area shown on Figure 6.5. Therefore, birds at a few locations would not only experience the maximum noise levels from the gunfire but also the shock wave associated with any sonic booms.

A summary of the noise characteristics calculated for the black grouse sites closest to GDAs Bravo/Charlie and Foxtrot is presented in Table 6.5. Due to the closer proximity of new gun spurs, the MaxP dBLin from AS90 would rise by approximately 8 dB near GDA Bravo/Charlie compared to the FH70, and by up to 14 dB near GDA Foxtrot. Most of the sound energy, as for FH70, would be below 250 Hz (see Chapter 3). Maximum noise levels from the firing of MLRS would be lower due to the greater distance to the nearest MLRS gun spur, and most of the sound energy would be below 1,000 Hz (see Chapter 3). However, the passage of the rockets at supersonic speeds could generate sonic booms, when most of the sound energy would be below 100 Hz (see Chapter 2). Unfortunately, no account has been taken by the MoD of the possible noise levels due to sonic boom effects and no noise data is available. However, the latest distribution data for the black grouse indicates that many of the black grouse locations are likely to be beyond the area subject to the direct effects of sonic booms.

Table 6.5: Predicted noise characteristics at black grouse sites due to proposed development

Source	L_{Amax} dB	MaxP dBLin	Frequency
AS90	-	136	Most sound energy below 250 Hz
MLRS	-	Sonic boom	Most sound energy below 100 Hz
Apache	>90	-	Most sound energy below 500 Hz. Greatest energy above 1000 Hz occurs when hovering.

Noise levels due to Apache training will be dependent on the aircraft's manoeuvres and height. Since most of its training will involve low-level flying and surprise attacks over ridgelines, noise levels at ground level are likely to be greater than 90 dB L_{Amax} (noise data in Chapter 3). The noise level differences between the Apache WAH-64, the US Apache AH64 and Lynx helicopters, indicates that L_{Amax} noise levels due to aircraft movements above black grouse habitats could be 3-7 dB higher than the present circumstances. Most of the Apache sound energy is below 500 Hz (see Chapter 3), although a significant increase in sound energy above 1,000 Hz occurs when the helicopter is hovering (unpublished data).

Phoenix noise levels are relatively low, tending to range from 35-55 dB(A) at ground level whilst the aircraft is flying. Noise levels above the 80 dB screening threshold are only encountered over a relatively small area close to the launcher during take-off.

Step 8 - Define study area re: noise transmission characteristics, ambient noise levels and species distribution

In this instance, the study area is largely defined by the known locations of black grouse at Otterburn. Significant peak noise levels, especially low frequency, will be caused beyond the range and also beyond the park boundary by the firing of AS90 and MLRS but the range of noise levels will be similar to FH70. Apache helicopters will also produce noise effects beyond the range whilst they fly to and from their training exercises, however, similar effects off-range would arise from Lynx helicopters. There may be locations beyond the range where sensitive species might be present, however, source noise levels will on the whole be lower and ambient noise levels tend to be higher beyond the range, which should lessen the noise impacts. Therefore, with the recorded black grouse locations being on the range, the study area can be limited to the range.

Step 9 - Establish hearing sensitivity of animal species and behavioural traits

Published data on animal hearing ranges and sensitivities has been summarised in Table 2.1. There is no data specific for the black grouse (although the low frequency limit for spruce grouse is shown as 80 Hz) and that available for birds in general shows a range of from 80 to 11,000 Hz with the greatest sensitivity occurring between 1,000 to 5,000 Hz.

Behavioural traits peculiar to the black grouse are as follows. The bird generally prefers open moorland habitats, and its nests are at ground level, so the animal will be particularly exposed to noise from aerial sources such as MLRS rockets or Apache helicopters. It is also a sedentary bird, and with short wings only makes short, low flights. Courtship occurs between April to May when males compete for females at communal mating grounds or leks. The males defend small mating territories within the lek, which females visit solely for the purpose of mating. The first mating call of the day usually occurs at approximately ½ hour before sunrise, and displays continue until approximately 9 or 10 am. Incubation of the eggs lasts 4 weeks and the chicks are able to walk and feed themselves soon after hatching[383]. As with most ground-born hatchlings, they must be able to run, hide and hunt for themselves almost immediately. In fact, grouse nestlings react to the silhouette of a hawk without being taught, and scatter into whatever cover is available. It appears that the ground birds react to the unknown rather than to a pre-programmed shape[384].

Female black grouse confer great reproductive success on some males, whilst ignoring others[385]. The most attractive males also have survival rates that are twice that of the least attractive individuals, which suggests that at least for grouse, the new offspring will receive 'strong genes' as a consequence of the female's choice to mate with the most attractive bird. A large proportion of the national losses comprise many of those males that are unsuccessful in securing an individual territory within the lek to mate.

Step 10 - Assess effects using significance criteria (no effect/slight/moderate/severe) and, where appropriate, formulate control measures

A summary assessment of estimated effects likely to arise from the combination of the development's noise levels and the black grouse's behaviour patterns is presented in Table 6.6. The assessment uses the significance criteria defined in Table 5.1 and for ease of reference, those assigned in this case are repeated below the table because they contain important guidance on whether animal responses will be seen as harmful or having long-term adverse effects.

Table 6.6: Summary assessment of OTA noise impacts on black grouse

Source	Effect	Significance
AS90	Some higher peak noise levels than FH70, but equally, due to the larger number of gun spurs, some AS90 firing will be further away than FH70 and hence cause lower noise levels. Some impacts likely but not expected to be too dissimilar to existing effects.	Slight
MLRS/ rocket propulsion/ sonic boom	Due to greater distance to MLRS gunspurs, noise from firing MLRS will be less than both AS90 and FH70. Therefore, noise effects would be no worse than existing artillery firing. However, in the event of sonic booms being caused by the passage of the rocket, these would be a new noise characteristic for range animals, and peak noise levels are likely to be higher than those due to either firing FH70, AS90 and MLRS, or the explosion of shells/rockets within the impact area. Therefore, impacts would at least be slight with a risk of becoming moderate long-term.	Slight (unknown risk of Moderate)
Impact area	With a greater use of indicator and non-HE rounds, noise from the impact area should be no worse than historical levels of training.	No effect
Apache	Noise levels would be similar to but slightly higher than Lynx helicopters, although noise effects of on-board rockets would again be a new noise source that has not been assessed. Noise at the bird's most sensitive hearing frequencies occurs when Apache is hovering, therefore such operations would be best excluded from above or around the black grouse habitats.	Slight (unknown risk of Moderate)
Phoenix	This represents another new noise source for animals on the range but as long as the launcher is not located within 250m of the black grouse habitats noise levels would remain below the screening threshold of 80 dB(A) and any effects would be no worse than slight. At Phoenix's usual cruising height of 700m its wingspan of 5.5m would, for an animal on the ground, appear the same as that of a hawk's circling at altitudes of 90-235m[386], which could cause chicks and birds to scatter. However such effects would be intermittent and birds would recover as they do from the natural response to the real-life presence of hawks, therefore, the effect would again be no worse than slight.	Slight
Overall conclusion	**Slight impact, but some precautionary controls and further study are required to ensure moderate effects do not arise.**	

Definitions (from Chapter 5):

No effect	Exposure to noise produces no recorded effect. In the above assessment, 'no effect' has also been used when the effect is no different to that caused by the existing circumstances.
Slight	Noise causes a reaction, whether physiological or behavioural, but animal returns to pre-exposure conditions relatively quickly and without continuing effects. The reaction may include movement such as flight or running away from the source but not to the extent that animals leave home territory. The response may also involve increased energy expenditure but not to the extent that it cannot easily be recovered after exposure. Many noise exposures such as aircraft overflights can produce the above reactions, but the event is limited in time and allows ample time for recovery either between individual events or on other unaffected days.
Moderate	Noise will cause many of the responses observed under the 'slight' category but they are carried a stage further by causing more permanent changes that do not allow individuals or communities to readily return to pre-exposure conditions. For example, exposure may cause animals to leave their home territory or feeding grounds permanently; or lead to decreased feeding, fertility or reproductive rates; or reduce flock sizes or population numbers. The long-term consequence of these effects may be uncertain, for example it could if sustained lead to harm to individuals and to local communities, which would eventually be a severe response, but such adverse effects are not immediately obvious.

In the case of black grouse, the assessment indicates that the actual point of firing of MLRS and the explosions of shells/rockets in the impact area, are considered to have no effect, i.e. no change to existing circumstances. The firing of AS90 and the operation of Phoenix would at worst have slight effects, but the events would be limited in time and should allow ample time for recovery either between individual events or on other unaffected days. Any sonic booms associated with MLRS rocket propulsion, or the operation of Apache above or around black grouse habitats, are likewise considered to have slight effects, but with an unknown risk of becoming moderate long term.

The overall effect, therefore, is considered to be slight but the presence of some new sources that have not been fully evaluated (rocket sonic booms, and Apache operations/aerial rocket launches) are considered to present an unknown risk that if not investigated fully might lead to moderate effects.

The assessment's conclusion is that the proposed operations at OTA would have a slight effect on the black grouse population. The guidance of the proposed assessment procedure for a slight effect is that 'mitigation is not compulsory but precautionary/observational measures may be required'. In this respect, the assessment summarised in Table 6.6 has identified two areas (noise from rocket propulsion/sonic boom and from Apache training) that have not been fully evaluated due to insufficient data. Therefore, there is an unknown risk of the extent to which responses might be moderate. As a consequence, in this case, further precautionary/observational measures are warranted.

If the overall conclusion had been slight without any areas of uncertainty, there would be no need for compulsory mitigation and also no need for other precautionary measures. However, this does not mean that mitigation cannot be applied at the discretion of the developer or if jointly agreed between the developer and the planning authority, since mitigation can always be discretionary when not compulsory. The precautionary measures proposed as a direct consequence of the assessment summarised in Table 6.6 are set out below, followed by those mitigation measures proposed at the Inquiry and by the SoS's conditions and the MoD's undertakings.

6.4.2 Precautionary Measures

In many instances of military aircraft training above parklands where sensitive animals are known to live, conditions have been imposed to maintain a minimum separation distance when overflying such sites. Unfortunately, where Apache training is concerned, this aircraft is specifically designed to fly low to be hidden by the terrain and to finally rise above the landform when attacking. To maintain a minimum separation distance AGL from sensitive animal communities is not a practicable solution without avoiding the area entirely. Therefore, until further study determines differently, it is recommended that Apache should not hover above or in the vicinity of black grouse locations, and that helicopter operations should ideally avoid the locations by at least 1,000m (the screening threshold distance).

The other identified risk stems from the movement of rockets at supersonic speeds over or close to black grouse. There is insufficient data to fully evaluate likely effects, therefore, immediate monitoring of peak noise levels and air over pressures is recommended at black grouse locations during all MLRS training exercises coupled with a long-term study of population numbers to ensure that the developmental effects do not shift from the slight to moderate categories. If a trend towards a moderate effect were to be identified, further mitigation measures would need to be devised.

6.4.3 Mitigation Measures

In the absence of man-made gunfire noises etc., the black grouse's courtship period and the communal mating grounds represent the most important aspects of the bird's lifespan when either reproduction with a strong male will be successful or weaker males will either die in competition with the stronger or not succeed in securing territory for mating. The decline of the black grouse has been shown to be fastest in those areas with poor breeding success. Therefore, it is most important to protect the lek areas and limitations on firing between April to May, and most especially between dawn to approximately 9-10 am when courtship displays are at their peak, would remove the likelihood of adverse impacts arising.

In response to specific points raised by NNPA[387], the MoD gave the following response applicable to their activities close to known leks of black grouse:

The main lekking period for black grouse is early in the breeding season (April-May). Lekking commences at dawn and diminishes in intensity as the day goes on. ...the normal live firing periods at Otterburn from 1st March to 31st October are from 0900-1700 and 2000-2400 and so under normal conditions there should be little additional disturbance to the lek as a result of firing from GDA Bravo/Charlie. On some occasions firing may occur outside these hours as is currently the case.

Of the conditions that accompanied the SoS's approval of the development, only two specifically dealt with limiting noise impacts on animals by preventing construction and military training in identified sensitive areas during the period 1 April to 30 June, which broadly covers both lambing and nesting periods. Of the MoD's stated 'undertakings' that would be implemented on planning approval, the key one for nature conservation was to undertake a monitoring programme for birds in accordance with agreements reached with English Nature, RSPB and Northumberland Wildlife Trust. Monitoring requirements for red squirrels and other species will be determined by an Environmental Steering Group (ESG), which comprises representatives of Land Command, NNPA, NCC, the Countryside Agency, English Nature, English Heritage, Environment Agency, the Commandant OTA, the Senior Land Agent and the MoD Conservation Officer.

Should the monitoring process identify significant adverse effects, the MoD will give due regard to remedial actions that may be recommended by the ESG. It is important to note that remedial action cannot and is not guaranteed, therefore, even if adverse effects are observed, factors such as 'national need' may over-ride them. Nevertheless, it is important that any adverse animal responses or trends in population numbers etc. are identified as soon as possible so that if remedial action is practicable it too can be taken as soon as possible.

Of six undertakings that related specifically to noise, most of these related to minimising impacts on human populations around the range. One related to wildlife and stated "wherever possible and commensurate with the achievement of training objectives, the MoD will endeavour to minimise its activity in sensitive areas during the bird-breeding season". However, once again, a factor 'commensurate with the achievement of training objectives', and use of the term 'endeavour', enables adverse effects to be permitted at the MoD's discretion.

With respect to livestock on the range's farmsteads, the following undertaking was given. "The MoD will agree a programme for monitoring the welfare of livestock with the local planning authority and State Veterinary Service of the Ministry of Agriculture, Fisheries and Food, and will carry out the agreed programme. ...Should adverse effects arising from the noise of artillery be identified, the MoD will take advice from the State Veterinary Service with respect to measures to protect animal welfare." This undertaking implies greater concern by the MoD towards the welfare of livestock compared to wildlife. Yet the analysis of animal responses undertaken in Chapter 5 demonstrates farm animals to be less sensitive to noise effects than wildlife, so in effect, greater concern should be displayed towards protecting wildlife. It seems likely that this undertaking was driven more by public pressure from the farmers themselves and their need to protect their business investments (possibly with a view to compensation) than any altruistic concern for the animals. However, long-term monitoring of actions under this undertaking might provide a useful means of detecting adverse effects on wildlife because the lesser sensitivity of livestock would suggest that if adverse effects arise, they are likely to be repeated but at a worse level within certain species of wildlife.

6.4.4 Case 2 – Golden Plover

To demonstrate that the assessment procedure can lead to different conclusions for other animals and circumstances, case 2 considers the effects of the OTA proposals on a second species, the wading bird golden plover. When repeating the steps of the assessment process it is only necessary to loop back to step 4 because the decisions as to whether an assessment is required (steps 1, 2 or 3) will remain the same. Equally, the information for some of the other steps may be common to case 1 or to other species assessed.

Step 4 - Establish local, regional, and national population bases for golden plover.

The RSPB survey at OTA recorded 25 pairs of golden plover, i.e. similar to the numbers of black grouse, and these tend to be located on the heathland habitat to the south/centre of the range over which the MLRS rockets would fire. The British Trust for Ornithology's survey of 1968-1972 is reproduced in Figure 6.7.

The number of 10-km squares across the UK in which golden plover were recorded was 915 or 24% of the country. Of the 915, 65% were confirmed breeding sites, 23% were probable and 12% were possible breeding grounds. The census information indicates a population at that time of between 51-75 birds at OTA. The data from the 1988-1991 survey is presented in Figure 6.8.

Figure 6.7: UK golden plover population density, number of birds in each 10 km^2, 1968-1972[381] (small black dot=1-25, medium dot=26-50, large dot=51-75, square=76+)

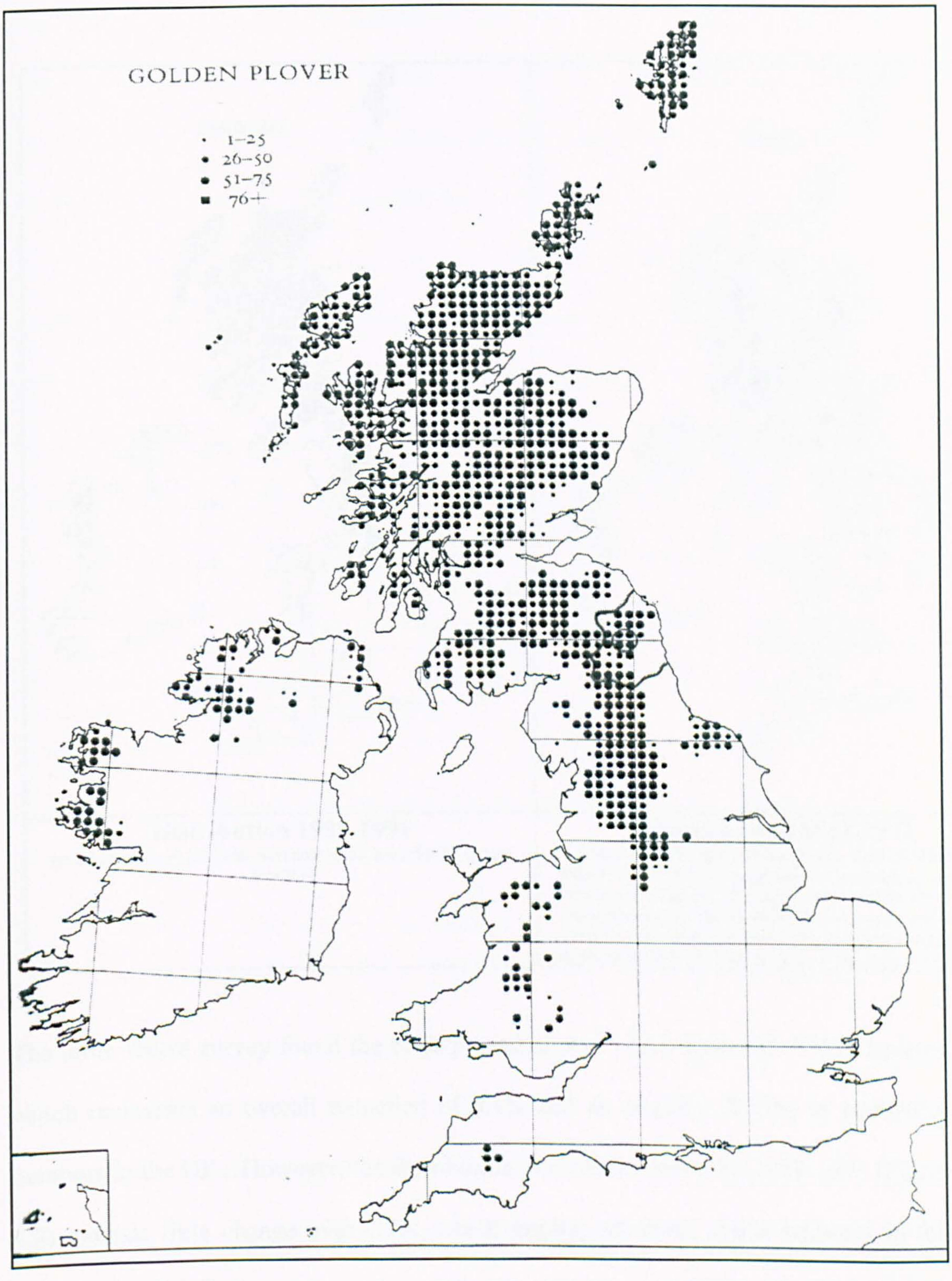
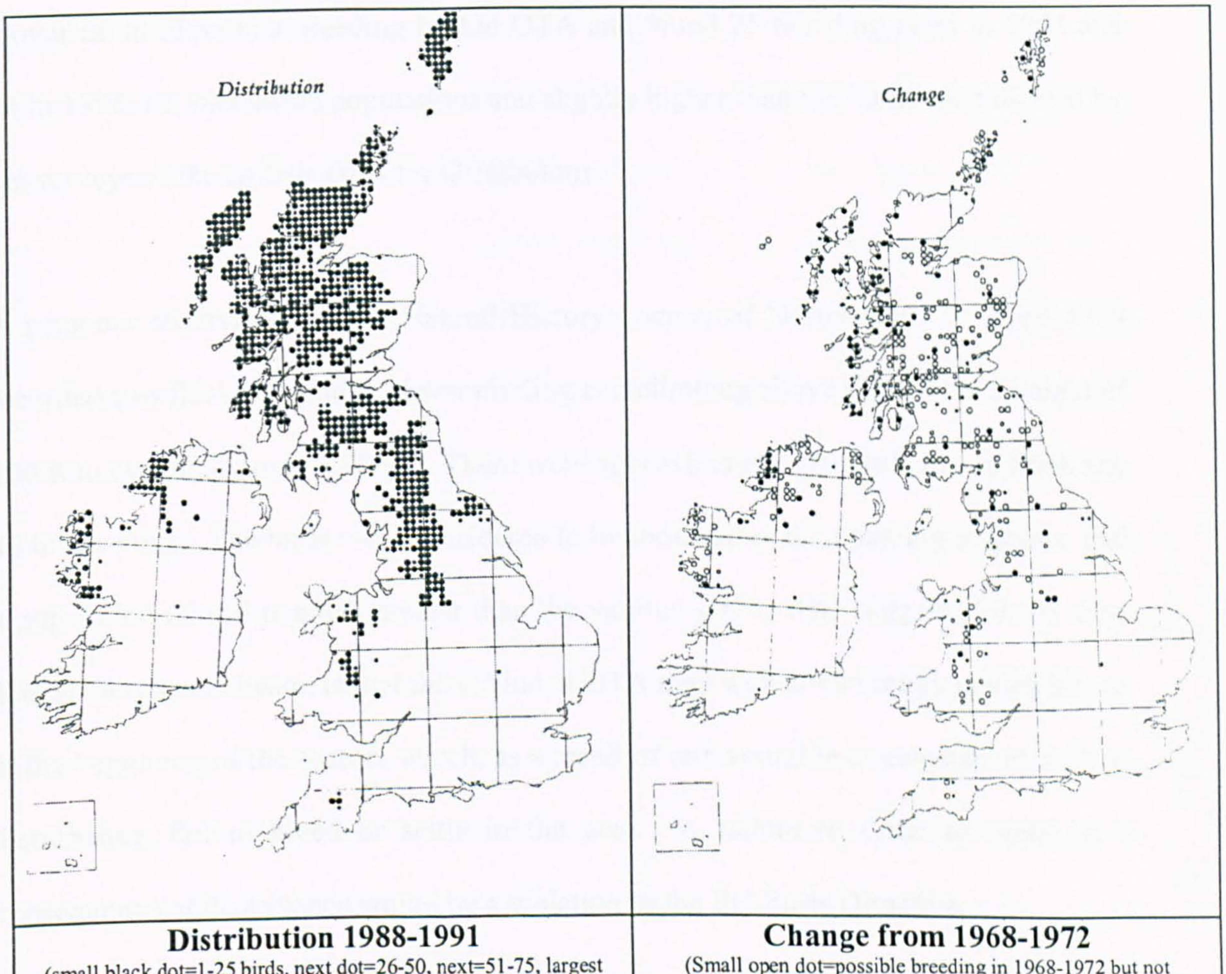


Figure 6.8: UK golden plover population density, number of birds in each 10 km^2, 1988-1991[382]



Distribution 1988-1991	Change from 1968-1972
(small black dot=1-25 birds, next dot=26-50, next=51-75, largest dot=76+)	(Small open dot=possible breeding in 1968-1972 but not recorded in 1988-1991; large open dot=probable or confirmed breeding in 1968-1972 but not recorded in 1988-1991; small filled dot=not recorded in 1968-1972 but present although no evidence of breeding in 1988-1991; and large filled dot=not recorded in 1968-1972 but evidence of breeding in 1988-1991.

The more recent survey found the birds present in 814 rather than 915 10-km squares, which represents an overall reduction of 8.1% and an ongoing decline in population numbers in the UK. However, the distribution and change maps for 1988-1991 (Figure 6.8) indicate little change over OTA, which implies relatively stable numbers in this area. The distribution information indicates that the population on OTA and its surroundings forms an important part of the County's overall population of golden plover.

The Otterburn bird surveys undertaken by RSPB for the Inquiry confirmed the golden plover as an important breeding bird at OTA and found 25 breeding pairs in 1994 and 34 in 1998, i.e. increasing populations and slightly higher than the numbers indicated by the surveys of the British Trust for Ornithology.

A personal observation of the Natural History Society of Northumbria in April 1999 recorded two flocks of golden plover circling and climbing above OTA from a height of 100 ft to eventually over 1,000 ft. There were approximately 120 birds in one flock and 40 in the other. The birds were considered to be local rather than passing migrants, and a population of 160 is much greater than the various survey data suggests for the area. The Society's conclusion is that the habitat at OTA may well attract many golden plover at the beginning of the season, which, as a result of unfavourable circumstances such as disturbance, fail to breed or settle in the area. A failure to settle or breed as a consequence of disturbance would be a violation of the EC Birds Directive.

Step 5 - Establish whether species has protected status.

Golden plover is afforded the following protection:

- protected under Annex I of the Birds Directive (79/409/EEC);
- key species under the Biodiversity Convention;
- vulnerable species in the British Red Data Book;

- protected under Schedule 2, Part 1 of the Wildlife and Countryside Act 1981; and
- protected under Appendix 10 of the Berne Convention.

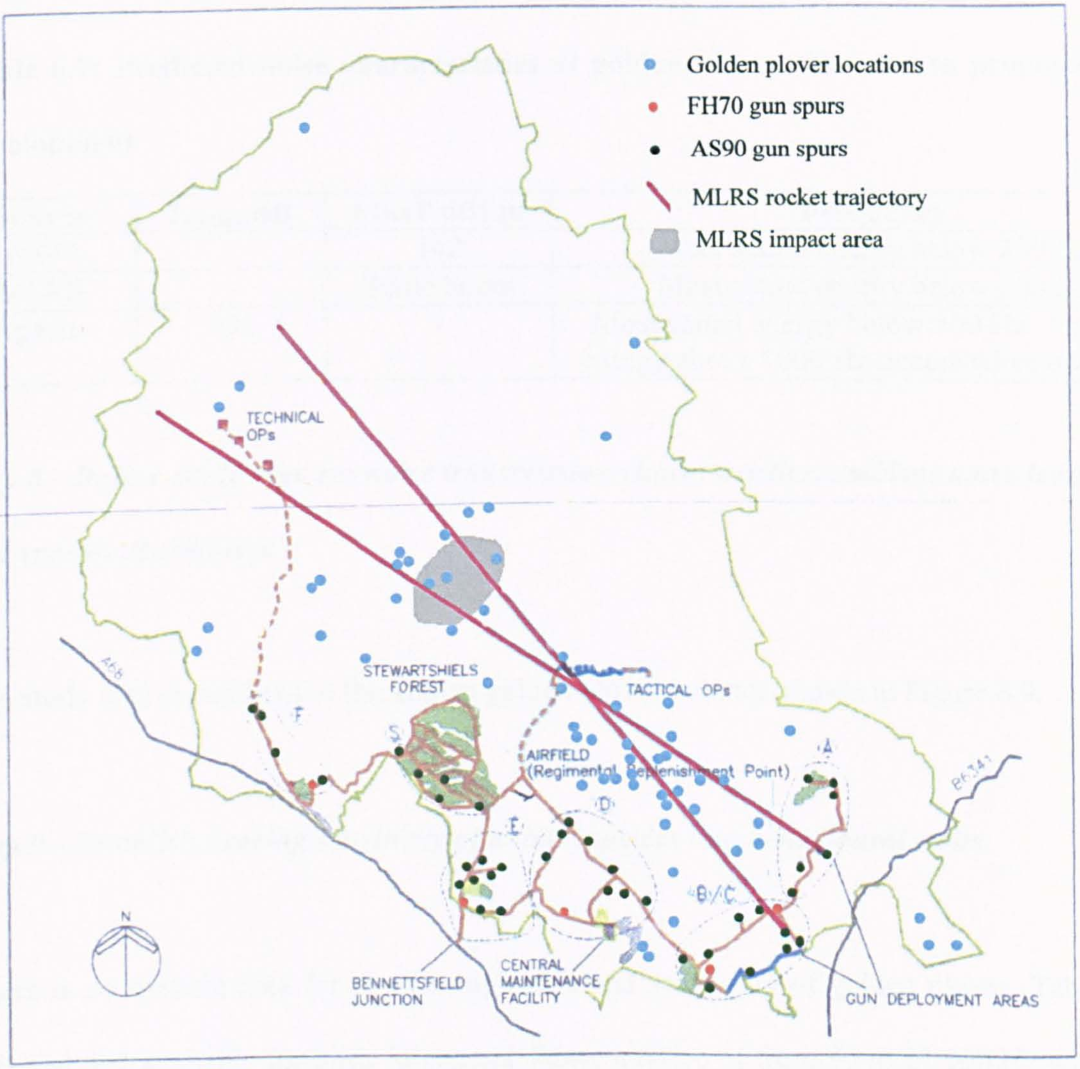
Step 6 - Establish existing noise climate

The existing noise climate for golden plover will be similar to that established for black grouse. The main difference is that the majority of the golden plover locations (recorded from the 1994/98 surveys and coloured light blue on Figure 6.9) lie to the south and centre of the range. The four existing FH70 gun spurs in this area each fire on average 763 155mm shells/year, making a total of 3,052/year. Predicted maximum noise levels at nearest golden plover habitats range from 122 to 136 MaxP dBLin.

Step 7 - Establish noise characteristics associated with proposed development

The noise characteristics associated with the firing of AS90 and MLRS, the passage of MLRS rockets through the air, the explosion of shells and rockets in the impact areas, training with the Apache helicopter, and flights of the unmanned Phoenix are as described for black grouse. The key difference is that MLRS rockets will be fired directly over the golden plover habitats, as indicated on Figure 6.9. Birds at these locations will, therefore, experience not only the change in noise due to nearer gun spurs but also the rocket propulsion noise and possible sonic booms as the rockets pass overhead.

Figure 6.9: Locations of OTA gun spurs, MLRS rocket trajectories, impact areas and areas occupied by golden plover



A summary of the noise characteristics calculated for the golden plover sites are presented in Table 6.7. Due to the closer proximity of new gun spurs, the MaxP dBLin from AS90 would rise by approximately 8 dB near GDA Bravo/Charlie compared to the FH70, and by up to 20 dB near GDA Delta. Maximum noise levels from the firing of MLRS would be lower due to the greater distance to the nearest MLRS gun spur, but noise from the flight of the rocket, including any sonic booms, would be much greater than that of 155mm shells and cannot be quantified due to insufficient data. Noise levels due to Apache training are likely to be greater than 90 dB L_{Amax} at ground level due to low-level flying and surprise attacks over ridgelines.

Table 6.7: Predicted noise characteristics at golden plover sites due to proposed development

Source	L_{Amax} dB	MaxP dBLin	Frequency
AS90	-	142	Most sound energy below 250 Hz
MLRS	-	Sonic boom	Most sound energy below 100 Hz
Apache	>90	-	Most sound energy below 500 Hz. Greatest energy above 1000 Hz occurs when hovering.

Step 8 - Define study area re: noise transmission characteristics, ambient noise levels and species distribution

The study area is confined to the known golden plover habitats shown in Figure 6.9.

Step 9 - Establish hearing sensitivity of animal species and behavioural traits

There is no specific data for the hearing range and sensitivity of golden plover (Table 2.1) and that available for birds in general shows a range of from 80 to 11,000 Hz with the greatest sensitivity occurring between 1,000 to 5,000 Hz.

Behavioural traits specific to the golden plover are as follows. The birds establish their territories from March and defend them through to early May when nesting takes place in hollows scraped in the ground. Every territory has a prominent, moss-topped look out hummock on which the off-duty bird stands guard. Nests tend to be at least 400m apart (5-8 pairs/km^2) and contain 3 or 4 eggs that hatch almost simultaneously. The birds are conspicuously marked when off their nests, but when sitting surrounded by pebbles and rocks their markings make them difficult to see. The parents usually take turns sitting on the nest and eventually divide the brood between them. The breeding grounds are vacated soon after the young fledge in mid-July.

Behavioural responses of golden plover to the firing of MLRS were observed during a demonstration when three missiles were fired. As the first missile was fired, a flock of approximately 50 golden plover were startled into flight approximately 1,000m ahead of the launcher and exhibited a pattern of irregular flight movements characteristic of predator evasion. As a consequence of ripple firing, the birds raised from the ground by the first missile were effectively very close to the flight of the second missile and would have been subjected to high noise levels that currently cannot be quantified. There is a possibility that in such circumstances noise levels may be high enough to cause a degree of hearing damage, which could be temporary or permanent.

Step 10 - Assess effects using significance criteria (no effect/slight/moderate/severe) and, where appropriate, formulate control measures

The summary assessment of estimated effects likely to arise from the combination of the development's noise levels and the golden plover's behaviour patterns is presented in Table 6.8. The overall conclusion is that the OTA proposals are likely to have a moderate impact upon golden plover and, under the proposed assessment methodology, mitigation would be compulsory. The moderate effect for the MLRS operations is based on the likely risk of some degree of hearing damage, and possible decreases to reproductive rates and population numbers.

Table 6.8: Summary assessment of OTA noise impacts on golden plover

Source	Effect	Significance
AS90	Peak noise levels due to firing AS90 will be higher than FH70 and many of the new gun spurs will be closer. Some impacts are, therefore, likely but the long-term effects are unknown.	Slight (unknown risk of Moderate)
MLRS/ rocket propulsion/ sonic boom	MLRS gunspurs tend to be at similar or greater distances than both AS90 and existing FH70. Therefore, peak noise levels during firing should be no worse than existing. However, rocket propulsion noise caused golden plover to be startled into flight, which placed them in the flightpath of subsequent rockets during ripple firing. The noise exposure of this response is likely to be high with a risk of hearing damage. Similar disturbance during the nesting season might cause egg predation, failure to incubate or territorial conflicts. Irregular use of MLRS at OTA means that birds are unlikely to habituate to the noise. In the event of sonic booms being caused by the passage of the rocket, these would also be a new noise characteristic for golden plover, and peak noise levels are likely to be higher than those due to either firing FH70, AS90 and MLRS, or the explosion of shells/rockets within the impact area.	Moderate
Impact area	With a greater use of indicator and non-HE rounds, noise from the impact area should be no worse than historical levels of training.	No effect
Apache	Noise levels would be similar to but slightly higher than Lynx helicopters, although noise effects of on-board rockets would again be a new noise source that has not been assessed. Noise at the bird's most sensitive hearing frequencies occurs when Apache is hovering, therefore such operations would be best excluded from above or around the golden plover habitats.	Slight (unknown risk of Moderate)
Phoenix	This represents another new noise source for animals on the range but as long as the launcher is not located within 250m of the golden plover habitats noise levels would remain below the screening threshold of 80 dB(A) and any effects would be no worse than slight.	Slight
Overall conclusion	**Moderate Impact**	

Since the noise assessment has considered the effects of the individual noise sources, it is possible to direct the mitigation at that element of the development expected to cause the adverse impact, namely, in this instance, the rocket propulsion noise from the firing of MLRS. Of the other components of development, the impact noises are considered to have no effect, and the operation of Phoenix only a slight effect, neither of which would require mitigation. The activities of AS90 and Apache are both considered to have slight effects but with caveats that would require the triggering of precautionary/observational measures to ensure that moderate effects did not result over time.

6.4.5 Precautionary Measures

With regard to precautionary measures against possible adverse effects due to AS90 and Apache, these would tend to be similar to those discussed for the black grouse, namely on-going observation, measurement and assessment during AS90 firing to ensure that adverse effects do not arise over time, and limitations on the operational distances between Apache and golden plover locations.

6.4.6 Mitigation Measures

With regard to compulsory mitigation against the moderate impact of MLRS firing, this could not be resolved through alternative siting of MLRS gun spurs relative to the golden plover locations, because the safety templates necessary for firing MLRS within the space available at OTA dictate the general position to the south and above the main areas of moorland where the golden plover nest. Not firing MLRS at OTA would be a solution but the MoD contended that there were no alternative suitable locations and 'national need' is a difficult argument to counter, especially when the OTA animal population is not of over-riding regional or national importance.

The most practical solution is, therefore, a restriction on MLRS firing during the period when golden plover are actively courting, nesting and rearing their young. This would cover at least the period from April to June inclusive. In this respect, the planning conditions accompanying the SoS's decision do prevent military training in identified sensitive areas during the period 1 April to 30 June, which would prevent the adverse impacts on golden plover during the crucial nesting season.

6.4.7 Summary

Application of the proposed assessment procedure has provided a better understanding of the likely areas of conflict between the proposed OTA development and the protected species chosen for study, and has enabled areas of potential adverse impact to be identified for further attention. In normal circumstances, steps 4-10 of the assessment process would be repeated for all other sensitive species that might be affected by new development. Some of the information may be common between different species, e.g. data relating to the existing noise climate and noise characteristics associated with the proposed development, but if the animal locations differ (as they do at OTA and probably will do at many other large sites since different species tend to occupy different habitat niches within the local environment) then the existing noise climate and noise levels due to the new development may be different and require fresh assessment.

The derivation of one of four different significance criteria to describe the overall impact and hence determine whether mitigation measures are needed, provides a degree of assurance that is often missing in noise impact assessments relating to wildlife. In many cases, the assessment will probably only need to deal with a single type of noise source and a single species. The situation at OTA is complicated by the presence of different noise sources having different noise characteristics, and also a multitude of sensitive species over a relatively large study area. In such circumstances, the final mitigation measures may need to reflect a compromise between several conflicting source-receiver relationships. For example, the mitigation needed to protect one species, e.g. using time or distance constraints, might adversely affect another whose sensitive temporal or spatial circumstances are different.

The mitigation measures applied to the OTA development are relatively basic in that conditions limit activity in identified sensitive areas during nesting and lambing periods, coupled with an undertaking that the MoD will endeavour to minimise its activity in sensitive areas during the bird-breeding season. For the black grouse, the normal period of firing heavy ammunition is also quoted as being outside the normal lekking period.

However, application of the proposed assessment procedure has identified other issues that are not covered either by condition or an undertaking, namely matters relating to operations of MLRS and Apache helicopter on the range. The assessment indicates that further study is warranted for these noise sources.

The use of simplified conditions such as that limiting noisy activity in identified sensitive areas during the nesting/bird-breeding season are likely to appear reasonable to those judging planning applications and their accompanying environmental assessments. However, the study of animal responses has identified that the actual response may vary from one species to another to the extent that whereas some birds may be sensitive whilst nesting, others may not and may be more sensitive once the young have left the nest. For this reason, it is considered inappropriate to use such wide-ranging conditions without first having considered the likely development's impacts on all sensitive species. As a similar example, the location of the black grouse predominantly within the northern half of the range, and the potential conflict between noise from Apache hovering and the bird's most sensitive hearing frequencies, suggests that Apache training would, at least for black grouse, be better confined to the southern area of the range. However, this compromise does not take account of the possibility of impacts on other animals located on the south of the range, e.g. golden plover, hence the need to fully consider all species and all sources before formulating mitigation measures and planning conditions.

Application of a formal assessment procedure will also help balance the measures applied to farm animals and those applied to wildlife. If it can be demonstrated, as it has in this research, that farm animals are less sensitive to noise than wildlife, then greater emphasis can be applied to those animals where protection is needed most.

6.5 CASE 3 - KIRKCUDBRIGHT WILDLIFE PARK

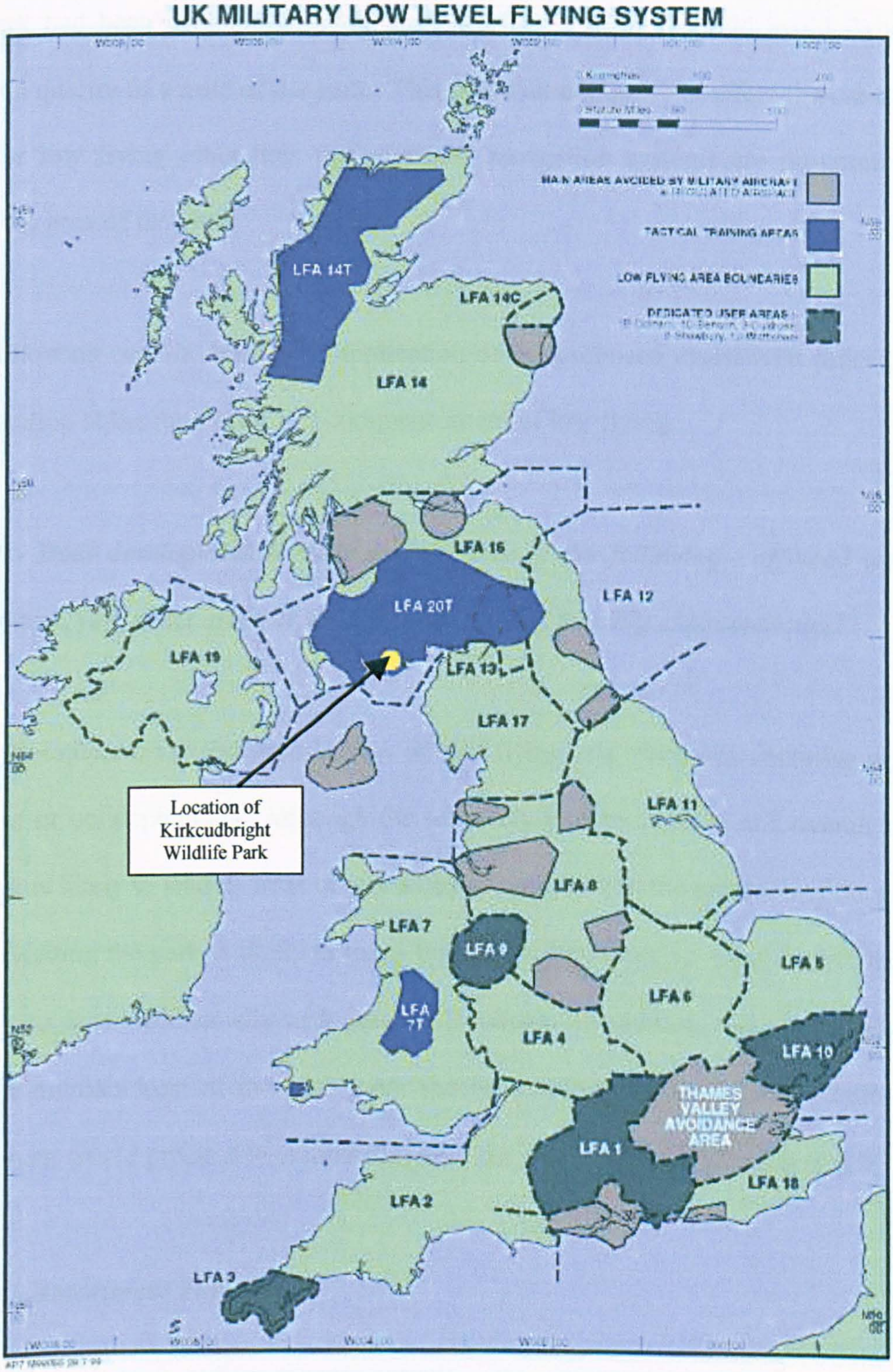
Application of the assessment procedures to the situation at the OTA has demonstrated how the procedures are intended to be applied. However, since the OTA development has yet to become operational, and no post-development studies have been undertaken, this test cannot be used to prove that the results obtained by applying the procedures are consistent with the actual noise effects. A better test of the procedure, is to apply it retrospectively to a situation where an adverse response was known to follow exposure to noise and, subsequently, noise was mitigated.

Finding a situation where adverse animal responses were known to arise following a specific noisy development was not a simple manner. I contacted specialists who are expert witnesses at planning hearings on matters relating to ecology but neither they nor their fellow colleagues had knowledge of any planning developments where subsequent noise impacts upon animals were known to occur. This lack of records seems to support the fact that the literature review uncovered relatively few severe responses. Some recent studies have indicated adverse effects for some marine mammals, such as changes to male humpback whale song following exposure to LFA sonar[388], and evidence of acute and chronic tissue damage in stranded cetaceans (predominantly beaked whales) caused by gas bubble lesions consistent with decompression sickness[389]. The latter case occurred, again, during a naval sonar exercise, which suggests that the high levels of low frequency noise, or the animal's responses to the noise, may have had a significant bearing on what was a 'severe' impact, though there is at present no direct link between the noise source and the effect. Other surveys have similarly found mass strandings of live whales coinciding in time and location with military tests of submarine detection sonar[390]. Unfortunately, application of the procedure to these situations would not test the main elements of the assessment procedure, which relate to land-based animals and which are most likely to be required for typical UK based planning applications. However, a suitable situation was eventually encountered in the form of military low-flying activities over the former Kirkcudbright Wildlife Park in southwest Scotland.

The Park (now under new ownership and renamed Galloway Wildlife Conservation Park) covers 25 acres of woodland and grass areas overlooking the River Dee and is involved in endangered species conservation programmes, which includes protection of the native Scottish wildcat and the European polecat. Other threatened species housed at the park include red pandas, South American bush dogs, collared peccaries, caracal and lynx. For a period of eight years the park was subject to low-flying by Royal Air Force Tornado jets, which were reported to frighten animals causing death and injury. The park reported[391] that a number of deer had died or injured themselves by running into fences after panicking at the noise of low-flying jets, and on one occasion that a baby red panda died after it was dropped when low-flying jets frightened its mother. Other incidents of importance from a safety point of view arose when staff were inside pens at the time of the noise disturbance and were placed at risk of being attacked by potentially dangerous cats that became frightened and aggressive after being startled by military jets.

In principle, the whole of the UK is open to low-flying military aircraft, but a number of areas such as airports, population centres, large industrial sites and conservation areas are excluded for safety and environmental reasons. Military fixed wing aircraft are defined as low flying when operating below 2,000 ft, although a small amount of low flying for fast jet and Hercules transport aircraft is permitted during the day at heights between 250 and 100 ft. The latter is only permitted in three Tactical Training Areas (TTA) over the UK[392], which are only activated at specific times each month. Kirkcudbright Wildlife Park lies within one of those located on the Scottish borders known as TTA 20T within Low Flying Area LFA 16 as shown in Figure 6.10. The MoD's operational timetable for the TTAs indicates that the busiest times for low flying are late spring and summer, and that most flying occurs during daylight hours during the central part of the day. In order to minimise noise during low flying, speed limits are imposed that restrict airspeeds to 450 knots, with an absolute maximum of 550 knots permitted for short dashes during simulated weapons attacks.

Figure 6.10: MoD's UK Military Low Level Flying Areas and Tactical Training Areas[392]



As a consequence of the adverse noise impacts caused by jets flying low over the wildlife park, both directly on animals and indirectly on park keepers from the risk of serious injury or death caused by frightened animals, the MoD confirmed in 2002 that the park had been declared an avoidance zone and that they would avoid flying jets within a quarter of a mile of the park. This commitment does not affect the use of TTA 20T for low flying other than that aircrafts' navigation systems are programmed to avoid the area of the park.

The following section deals with application of the proposed assessment procedure to the situation at the park prior to a commencement of low flying.

Step 1 - Does development include one or more of the following - off-road vehicles, helicopters, very quiet areas or animals with special hearing characteristics?

The development, i.e. the introduction of low flying jets, does not comprise off-road vehicles or helicopters and, although the relatively remote location and overall size of the park is likely to lead to areas of low ambient noise levels, the presence of the general public visiting the park is likely to mean that levels would not be equivalent to the very quiet areas associated usually with desolate locations. In addition, there is no indication that the animals kept at the park have special hearing characteristics, therefore, the assessment would proceed to comparison with the assessment threshold in step 2.

Step 2 – Assessment Threshold

The minimum altitude of low-flying military jet aircraft in the UK is typically 250 ft (76.2 m) although in designated TTAs such as that within which the park is situated, the minimum can be 100 ft (30.5 m). Noise data in Chapter 3 shows that the L_{Amax} noise levels due to Tornado jets flying at a height of 100 ft at speeds of 480 knots is approximately 124 dB. Therefore, given a height of at least 100 ft above ground level the resultant noise level will exceed the assessment threshold of 80 dB L_{Amax}. For an aircraft flying at 250 ft the noise level at ground level can be estimated by assuming spherical spreading only.

$$L_{Amax} \text{ at } 250 \text{ ft} = 124 - 20 * \log_{10}(250/100)$$
$$= 116 \text{ dB}$$

This will be a reasonable estimate for areas immediately beneath the flight path but will tend to give overestimates when ground effect, topography and meteorology result in shadow zones at the reception points of interest. Ground effect over flat ground should be included when the slant angle is 5° or less, i.e. the flight paths would have to be at a height of 100 ft or less at a range of 3,280 ft (1,000m) to give a sufficiently small grazing angle that ground reflection should be included.

However, whether the Tornados were flying at 100 or 250 ft above ground level the L_{Amax} would greatly exceed the assessment threshold of 80 dB beneath the flight path. In addition, the separation distances would also be less than the trigger distance of 1,000m (3,280 ft). For these reasons, further assessment is warranted and the assessment proceeds to stage 3.

Step 3 – Are noise-sensitive animals present?

The park is home to animals such as the red or lesser panda (*Ailurus fulgens*), endangered species such as the Scottish wildcat (*Felix silvestris*) and the European polecat (*Mustela putorius*), and various species of deer. The latter, e.g. fallow deer (*Dama dama*), roe deer (*Capreolus capreolus*) and red deer (*Cervus elaphus*) can be wary and shy, and when alarmed may often make off with leaps and bounds. Therefore, animals having various degrees of sensitivity towards noise or startling events are present and the assessment proceeds to step 4.

Step 4 - Establish local, regional, and national population bases for animals identified.

The red panda is not indigenous to the UK and has no local, regional or national importance within the UK other than as an attraction to members of the public, although internationally the panda is of significance since it is an endangered species. The wildcat is only found within Scotland in the UK but is also found in various countries throughout Europe[393]. It is mainly confined to the Scottish Highlands but, although rare in parts of its range, its range appears to be extending north and westwards. The polecat is restricted mainly to central Scotland, the border counties and central Wales[394] but it appears to be becoming more common with the decline in trapping. Deer are well established in many parts of the UK and are not endangered but do have their own protective legislation as discussed below.

Step 5 - Establish whether species has protected status.

The wildcat is protected under Schedule 5 of the Wildlife and Countryside Act, 1981, whereas the polecat is protected under Schedule 6. The red panda does not have any specific protected status within the UK, however, it is an endangered species and is protected and listed in Appendix II of the Convention on the International Trade in Threatened and Endangered Species. The legislative protection for deer relates to matters such as management, culling and poaching under the Deer Act 1991 and the Wildlife Countryside Act 1981 in England and Wales, the Deer (Scotland) Act 1996 in Scotland, and the Wildlife Order 1985 in Northern Ireland. Therefore, with regard to conservation, the wildcat has the greatest importance and protection status within the UK, but the red panda has the greater protected status internationally.

Step 6 - Establish existing noise climate

In the absence of military low-flying activities, existing ambient noise levels over the park will tend to be relatively low, although during the day there will be exposure to noise levels generated by the general public visiting the park or by staff during their daily routines.

Figure 4.3 (Chapter 4) indicates that the area is subject to annual average wind speeds of approximately 14 knots, i.e. 7 m/s. Table 4.6 indicates that at such speeds, wind through trees is likely to produce noise levels of 50-52 dB(A). Using equation 4.1 of Chapter 4 results in an L_{A95} of 42 dB, therefore, the background L_{A90} noise level will be similar but slightly higher than this. Figure 4.5 indicates that the area is subject on average to 8 days each year when lightning will be present and as a consequence animals will be exposed at these times to varying levels of peak noise due to thunder, which themselves will exceed the 80 dB(A) assessment threshold.

Step 7 - Establish noise characteristics associated with proposed development

The main noise characteristics at ground level due to low-flying Tornado aircraft are high L_{Amax} noise levels of typically 116 to 124 dB subject to the aircraft's altitude, and a rapid on-set rate, typically around 40 dB/second for jets flying at a height of 100 ft at speeds of 480 knots (552 mph). The presence of forested terrain, as would be the case around Kirkcudbright, can further increase the on-set rate for low-flying aircraft to 67 dB/sec[372]. At higher speeds the on-set rate will be much higher, e.g. at 526 knots (605 mph) a rate of 93 dB/second has been observed (see Chapter 3). Tornado speeds within the TTA would typically be 450 knots with short bursts of 550 knots. On the basis that aircraft noise with a rise time of 20 dB/sec or more is startling, tornados travelling at a height of 100ft and speed of 450 knots will have the capacity to generate startle effects over a lateral extent of 1,400 ft either side of the flightpath[372].

The MoD's published data for 1995 to 2002 for low flying by fixed wing aircraft in LFA 16 indicates that the average hours booked/year for day and night-time low flying amounts to 3,285. With an available yearly total of 8,760 hours it is evident that the hours booked represents a significant 37.5% of the year. Flying would be spread over the LFA's useable area of 16,142 km^2 (which represents 9% of the UK's total useable overland LFA), nevertheless, at the speeds that the Tornados travel the potential exists for large tracts of the LFA to be affected during each and every period of low flying. In addition, the presence of the Army training area at Kirkcudbright is likely to have increased the proportion of time when low flying aircraft would have been in the Kirkcudbright area for joint exercises and, therefore, close to the wildlife park.

Step 8 - Define study area re: noise transmission characteristics, ambient noise levels and species distribution

The study area is defined by the land used by the Kirkcudbright Wildlife Park and in particular the enclosures used by the species under consideration. The extent of the area will be relatively small and noise transmission characteristics, ambient noise levels and species distribution will not alter significantly from one point to another. For aircraft flying directly above the park, matters such as vegetation cover, topography and also meteorological conditions are unlikely to be significant factors in determining an animal's response to the noise although they may influence the noise on-set rate as discussed previously. Ambient noise levels in the absence of aircraft noise and park visitors are likely to be relatively low, although vocalisations of other animals may be significant.

Step 9 - Establish hearing sensitivity of animal species and behavioural traits

The data on animal hearing ranges and sensitivities in Chapter 2 indicates that the frequency range of hearing for the cat is from approximately 70 Hz up to 60,000 Hz. Chapter 2 does not have data on hearing sensitivity specific for the polecat, the panda or deer, but based upon the range of mammal audiograms all four species are likely to exhibit a broad and similar range of sensitivity.

The wildcat[395,396] is a secretive/solitary creature that is mainly nocturnal and generally sleeps in trees during the day, having sharp and retractable claws. It is more likely to be seen during daylight hours in autumn when the animal spends more time hunting in order to build up fat reserves for the winter. Wildcats rely mainly upon vision for hunting their prey but their upper limit of hearing allows them to hear ultra-sounds, which aids their tracking of small rodents. Mating occurs in late February, gestation lasts around 66 days and the litter of typically 3 kittens arrives in mid-April to mid-May. The kittens are blind at birth but can see after two weeks; their first steps are taken at about one month and they are generally independent at approximately five months.

The polecat is a member of the weasel family and is another nocturnal and solitary animal, with a home range of approximately 1 km^2. It shelters in hollows in stream banks, rocks or tree roots, where the female makes its nest. Breeding takes place in May-June and 3-4 pups are born after a gestation of 42 days. Their diurnal activity level is typically 30% in the wild for both males and females, although females spend more time foraging and males more time travelling[397].

The red panda[398,399] is a solitary raccoon-like animal whose sight, hearing and smell are not particularly developed. The animal is active between dusk and dawn, and sleeps in trees during the day. It is an excellent climber and escapes from predators by climbing high into trees, having sharp and partly retractable claws, which should be an asset when making rapid avoidance movements. The mating season is from January to March, with a gestation period of 90-150 days and births of 1 to 4 cubs occurs in May and June. In the wild, the female builds a nest by lining a tree cavity or rock cleft with grass in which the young stay for around 90 days; in captivity the nest may be a box, hollow log or other artificial den. The mother stays with the young for the first few days, and after one week she spends more time away from the nest, returning every few hours to nurse and groom the young and clean the nest. The young first leave the nest at night after a period of about 90 days.

Fallow deer[400,401] will often stand motionless until forced to move, e.g. due to the proximity of humans, and when eventually alarmed they bound off by bringing all four feet together, which leave the ground simultaneously. They tend to feed/graze at dawn and during late afternoon or evening, and in-between lie ruminating. If disturbed whilst feeding, panic running or bounding can be induced and animals tend to follow the dominant doe back into cover although mature males tend to run in a different direction. Rutting starts in August/September, reaching a peak in October, and does give birth to a single fawn, which is generally born between May and June after a gestation period of 31-32 weeks. The fawn remains in a hiding place in dense vegetation for approximately 4 months, with the doe returning every four hours to feed it, thereafter it joins the herd and is weaned after 7-9 months.

As with fallow deer, roe deer[402] will bound for cover if disturbed, and if regularly disturbed animals can become nocturnal. The digestive system of the roe deer is simpler than other deer species and as a consequence food passes relatively quickly through the digestive tract, which often necessitates more frequent periods of feeding. However, during late autumn and winter a reduced metabolic rate (a state of semi-hibernation) leads to reduced activity. If disturbance occurs at this time then an animal is more likely to be weakened due to energy expenditure coupled with less food intake, which is often of poorer quality at this time of year. The rut starts slightly earlier, between late July and August, and unusually the embryo undergoes delayed implantation[403], which means that it floats freely in the uterus and develops only slowly, and not until December/January does it become implanted in the uterine wall, after which rapid foetal development begins. Noise exposure during the period of delayed implantation might have more serious consequences than for a normal implanted embryo at the same stage of gestation, but further research is required to determine this. Roe kids or fawns are again born between May and June.

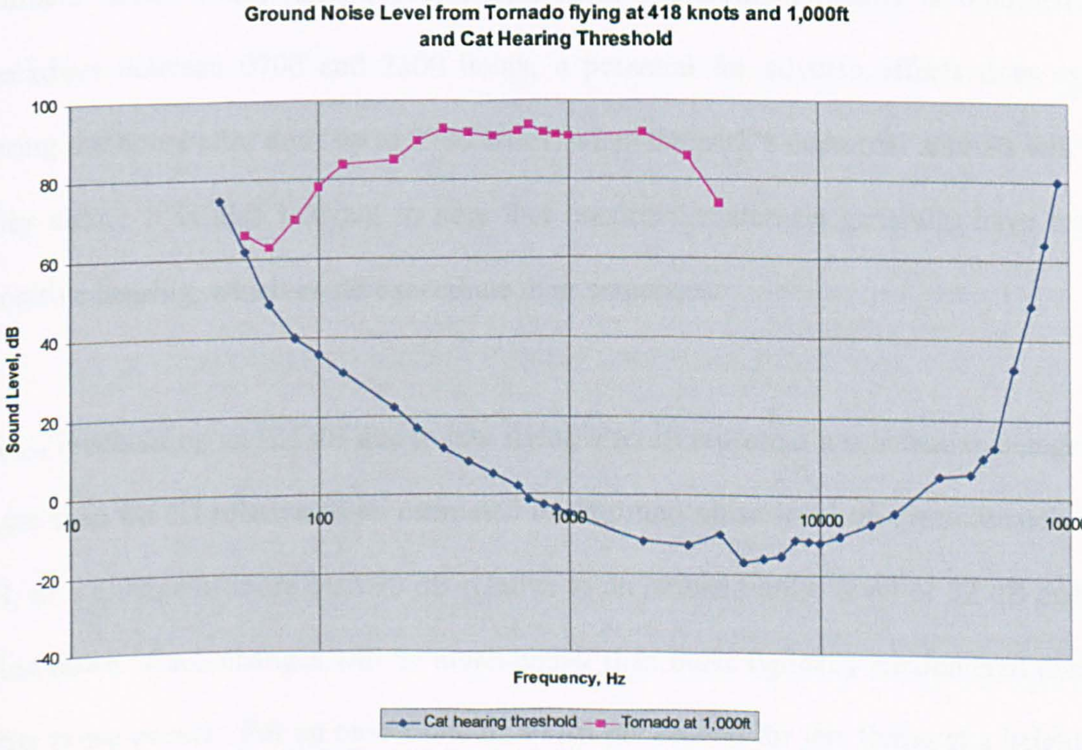
In the case of the red deer[404], approximately 300,000 live wild in Scotland. They were originally woodland dwellers but with the loss of forest landscapes have adapted to moorland habitats. In the wild they tend to spend the nights in lower, sheltered areas but move to higher sunnier ground during the day where they feed, rest and ruminate. Rutting activity peaks in mid-October and mature stags can lose up to 20% of their body weight during this period. The gestation period is approximately 32 weeks and calves are usually born in June.

Step 10 - Assess effects using significance criteria (no effect/slight/moderate/severe) and, where appropriate, formulate control measures

It is difficult to say with certainty that a given species or individual animal will react adversely to Tornado noise; reported responses are mainly anecdotal and generally relate to a one-off response by an individual animal, such as the recently reported case of a chow dog that leapt out of a first floor window and shattered its leg when a low flying Tornado passed overhead[405]. Of the possible types of environmental noise sources, the very high noise levels associated with low-flying Tornados, coupled with the rapid on-set rate, are probably the most likely to cause a startle effect, most particularly for animals such as deer that are prone to panic running.

Figure 6.11 plots the noise levels experienced at ground level from a Tornado flying at 418 knots and 1,000ft[372] (305m) against the hearing thresholds for the cat. At 1,000ft the Tornado noise is typically 100 dB higher than the lowest noise that the cat is capable of hearing. For aircraft flying lower than 1,000ft the difference will be greater still, therefore, there is little likelihood that normal background noises will have any interfering effects on the animal's detection and 'appreciation' of the intruding noise level. The level difference between the hearing threshold and the exposure level will be slightly less for the other species being considered (because the cat has one of the lowest thresholds of all the mammal audiograms presented in Chapter 2), nevertheless, the level will be substantially above the hearing threshold and, coupled with its rapid on-set rate, is most likely to generate startle reactions.

Figure 6.11: Tornado Aircraft Noise[372] Relative to Hearing Threshold of the Cat[271,272,273,274,275,443]



In the case of the wildcat, polecat and red panda, which are mainly nocturnal and spend most of the daylight hours sleeping, it seems reasonable to assume that daytime flying might have less of an impact upon nocturnal species because although an animal might be awakened, the very short event time might not enable the animal to become fully aware of the significance of what caused it to awaken. Further research is required to confirm this.

Although laboratory animals can tolerate high noise levels during sleep, this is usually after they have adapted behaviourally and physiologically[406], which is a process likely to require some lengthy or repetitive exposures. Once an animal has adapted to noises that originally caused awakening, subsequent exposures may cause some physiological responses, e.g. changes in REM sleep, but wakening need not necessarily occur. Sounds most likely to induce wakening are meaningful sounds, e.g. predator sounds or alarm calls, and also transient sounds having a high onset rate, into which category the Tornado noise would fall. Nevertheless, since low-flying typically is confined to weekdays between 0700 and 2300 hours, a potential for adverse effects does exist during the hours after dusk up to 2300 hours, when the park's nocturnal animals will be fully alert. It is also relevant to note that nocturnal mammals generally have more sensitive hearing, which could exacerbate their responses.

L_{Amax} levels of up to 124 dB due to low flying aircraft represent a substantial change of more than 80 dB relative to an estimated background noise level of approximately 42 dB, or a change of more than 70 dB relative to an ambient noise level of 52 dB due to wind noise. Such changes will be much higher than those typically encountered due to other noise events. For an on-set rate of 40 dB per second for jets flying at a height of

100 ft at speeds of 480 knots, the peak noise level would be reached within 2 seconds and, due to the speed of the departing jet, it is likely that the decay rate will be similarly rapid, although perhaps slightly longer since the jet exhaust will be facing towards the animal. Therefore, the total period of exposure to aircraft noise, bearing in mind that the initial onset and final decay stages will not be too dissimilar to the ambient noise levels, is unlikely to be more than 2-4 seconds. During this time, at a speed of 480 knots (equal to 552 mph or 245 m/s), the aircraft will have travelled between 0.5 to 1 km, therefore, the aircraft is unlikely to have been visible to the animal. Most of us will have experienced occasions when noise from low flying jet aircraft has been audible but we have been unable to locate the source, and this inability to locate the source is likely to be even greater for small animals that are close to the ground and screened by vegetation or other structures. Therefore, any response to the low flying events will be triggered by auditory rather than visual cues.

It is difficult to be precise over whether individual animals will or will not react to the types of noise events discussed above. However, the type of noise, its high level and rapid on-set rate are the sort of characteristics known to elicit startle responses, most particularly in the case of deer that are prone to panic running responses. As a consequence, I conclude that there would be a strong likelihood of startle responses occurring within some of the animals at the Park during Tornado overflights, which would tend to result in short period physiological or behavioural responses. Animals should revert to the normal physiological state within a relatively short period of time depending upon the baseline health or nervous disposition of the animal, and also subject to recurring noise exposure to other aircraft overflights, which could in turn produce habituation.

A behavioural response is most likely to materialise as panic running, and since the animals are confined to enclosures, this may lead to collisions with fences, posts, trees or other fixtures within the enclosure. Of the different species being considered, the deer, being animals that run for cover, are most likely to collide with trees or fences etc. and the risk of injury is considered to be high. The wildcat and red panda are more likely to run up the nearest tree rather than into it and it is important to recognise that both creatures are arboreal and use their claws to rapidly climb trees for refuge. Therefore, their natural instinct, if awake and at ground level during the noise exposure, is likely to be to climb a tree for security, by which time the event will be over. Only panic running is likely to cause harm due to collision impacts, but the very short duration noise events associated with single low flying aircraft should not lead to such a response being sustained for long. Several fly-overs in short succession might lead to longer periods of panic running, perhaps with more sudden turns to 'escape the noise', which would lead to a greater risk of collision impacts for the deer.

Where the animals are resting/asleep, which is more likely to be the situation for the majority of overflights, I consider the response is likely to be less dramatic for the reasons discussed previously, i.e. the awakening/coming alert response is likely to be the first reaction, by which time the event will be past. However, successive exposures, for example during operational training involving several aircraft, would exacerbate the responses during both the resting and awake stages. Due to the wildcat, polecat and red panda possessing sharp claws that enable them to hold tight to the surfaces they are in contact with, it is unlikely that adults sleeping in trees or other high nesting areas would suffer harm by being startled and falling to the ground. The greatest risk is likely to arise during the breeding periods when young within high nest areas could be dislodged or dropped by nursing mothers that are startled. In this respect, the red panda is probably more at risk by virtue of the longer time the young spend in the nest and the more time the mother spends nursing and grooming them. A summary assessment of estimated effects likely to arise from exposure to low flying jet aircraft is presented in Table 6.9.

Table 6.9: Summary assessment of noise impacts of low flying Tornado aircraft on sensitive animals at Kirkcudbright Wildlife Park

Source	Effect	Significance
Tornado	Red Panda: Due to the very high noise levels with rapid on-set rates, startle responses are likely. Risk of harm due to collision impacts is likely to be reduced due to i) animal being mainly nocturnal and hence often asleep during daytime overflights, and ii) the animal is arboreal and naturally uses its claws to rapidly climb trees for refuge. In the absence of night-time flights, flights at dawn and dusk would have a potential to startle the animal during its awake and active state. The greatest risk is likely to arise during the breeding periods when young within high nest areas could be dislodged or dropped by nursing mothers that are startled.	Slight to Moderate but risk of Severe during breeding season.
	Wildcat: Due to the very high noise levels with rapid on-set rates, startle responses are likely. Risk of harm due to collision impacts is likely to be reduced due to i) animal being mainly nocturnal and hence often asleep during daytime overflights, and ii) the animal is arboreal and naturally uses its claws to rapidly climb trees for refuge. In the absence of night-time flights, flights at dawn and dusk would have a potential to startle the animal during its awake and active state.	Slight to Moderate.
	Polecat: Due to the very high noise levels with rapid on-set rates, startle responses are likely. Risk of harm due to collision impacts is likely to be reduced due to animal being mainly nocturnal and hence often asleep during daytime overflights. In the absence of night-time flights, flights at dawn and dusk would have a potential to startle the animal during its awake and active state.	Slight to Moderate.
	Deer: Due to the very high noise levels with rapid on-set rates, and the behavioural characteristics of these animals, startle responses involving panic running are probable. Since the animals are contained within enclosures, the potential for collision with fences, posts, trees or other fixtures within the enclosure is increased, and the risk of injury is considered to be high.	Moderate to Severe
Overall conclusion	**Variable effects expected, ranging from Slight to Moderate for the red panda, wildcat and polecat, with a risk of Severe for the red panda during the breeding season, and Moderate to Severe effects for deer. Some controls are required to prevent Moderate to Severe impacts.**	

The summary assessment in Table 6.9 results in similar responses for each species, namely, variable effects are to be expected ranging from slight to severe subject to the degree of panic response initiated as a consequence of startle. The risk of severe impacts are likely to be greatest for the deer as a consequence of panic running but risks of severe responses are also considered possible for the red panda during the breeding season. However, the fact that the animals are captive means that the proposed significance criteria for assessing an animal's response to noise (see Table 5.1) are likely to be applied somewhat differently to animals in the wild. For example, being 'captive' means that animal responses cannot affect changes to home territory and also that care in the form of food and medical attention will always be provided by the park operators so that the animal's ability to fend for itself becomes less important.

Slight effects will always arise as a consequence of either physiological or behavioural responses, and this may include attempts to 'run away from the noise source', which will incur energy expenditure, but the overflights would be limited in time and, in the absence of collision impacts, there would be ample time for recovery either between individual events or on other unaffected days. In the wild, a moderate effect could be associated with an ability to return to pre-exposure conditions after a response such as a change of territory or feeding ground, but this type of response is no longer a possibility within the captive environment of a commercial parkland, although effects such as decreased feeding, fertility or reproductive rates could still materialise. The fact that day to day 'care' is provided by the park operators may mean that the responses for all captive animals are more likely to fall at the extremes of the assessment scale, i.e. either slight or severe with no or few moderate effects.

For a slight response, the assessment procedure recommends that mitigation is not compulsory but precautionary/observational measures may be required, and discretionary mitigation is permissible. For moderate and severe responses, mitigation measures would be compulsory.

6.5.1 Precautionary Measures

The responses associated with exposure to noise from low flying jet aircraft tend to be either instantaneous and obvious, i.e. a typical startle reaction, or non-existent, i.e. no visible reaction. As a consequence, precautionary mitigation measures, which may include routine observation and appropriate action if necessary, are not a realistic solution. Since, in the situation being considered, responses are most likely to be either slight or severe, and slight responses do not cause long term or harmful responses, it is evident that if an adverse effect is to be prevented at the wildlife park then a mitigation measure is required that will prevent the possibility of collision impacts, which includes not only animals colliding with hard or sharp surfaces but also young being dropped and hence hitting the ground. In this case, the only precautionary measure is one that prevents a startle response. There is nothing that can be done at the animal position to prevent exposure to the high noise level from Tornado aircraft that initiates a startle response because insulating the park or its enclosures against sound is not a practicable solution nor would it be consistent with park policy that aims to keep animals in open and natural habitats. Therefore, the only effective solution is to remove the noise source.

6.5.2 Compulsory Measures

With regard to preventing severe responses, the only effective solution must again be the removal of the noise source. Removal can be achieved by preventing low flying aircraft flying over or near the wildlife park in co-operation with the MoD.

6.5.3 Summary

The likely responses determined by the assessment procedure, namely animals being panicked by jet noises and injuring themselves or their young through collision, are consistent with the actual impacts reported by the park[407]. The proposed mitigation, i.e. the avoidance of the wildlife park by low flying aircraft, is also consistent with the eventual steps taken to resolve the noise impacts caused by low flying aircraft. Therefore, it has been demonstrated that the results and recommendations obtained by applying the proposed assessment procedures are consistent with the actual noise events.

7. CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

The literature review undertaken for this research has demonstrated wide ranging responses within animal communities following exposure to noise but, although adverse impacts can arise, the overwhelming evidence indicates that animals are surprisingly resilient to noise and that in most cases physical harm or long-term adverse effects are unlikely to materialise. The absence of documented cases within the UK where new developments have subsequently been found to cause adverse effects on animals supports this finding. The evidence also indicates that domestic and farm animals have the greatest resilience towards noise.

Nevertheless, there is a statutory requirement to protect certain animals and to assess the environmental effects of new developments on wildlife. There is no formal guidance on how such assessments should be undertaken, and all too often when an assessment is undertaken it takes the form of a brief literature review with little specific detail relating to either the form of development or the behavioural characteristics of the species of concern. As a consequence, there is often inadequate information on which to reach a properly informed judgement as to the likely short or long-term impacts on animals, which can make the correct forms of mitigation difficult to define.

This research has developed an assessment process specific to animals, which fills the present gap in Environmental Assessment guidance and will help focus assessor's minds on the key elements that need to be considered during and after an assessment. A review of published animal responses arising from exposure to different noise sources and levels illustrates how the responses can be wide ranging even within the same species. However, the data has been analysed to identify particular trends and response thresholds, and it is this information that has been used to develop the set of standard procedures for assessing noise effects on animals. Significance criteria have also been developed for use in conjunction with the assessment procedures. The criteria – no effect, slight, moderate and severe - take account of the physiological and behavioural responses exhibited following exposure to noise, and the significance rating is used to determine whether mitigation is required.

The analysis of responses has also identified particular combinations of noise, animals and habitat that are especially sensitive to environmental noises and hence present a high risk of adverse impact occurring. The factors causing the greatest sensitivity to noise are off-road vehicles (ORV), e.g. trail bikes, dune buggies etc., helicopters, very quiet habitats such as desert and scrubland, and animals having special hearing characteristics. These four factors form the first decision-making step in the proposed assessment process.

The analysis of animal responses has also been used to develop an assessment threshold based on important factors such as the noise level, distance from the noise source, and other identified site-specific circumstances. If L_{Amax} noise levels are equal to or greater than 80 dB or the separation between the animals and the noise source is less than 1,000m, an assessment is recommended. For fish and marine mammals, if the Received

Level (RL) is greater than 140 dB re: 1μPa rms an assessment is recommended. Slight responses may still arise below these thresholds but moderate or severe responses having significant adverse effects on local animal populations would not be expected. Circumstances most likely to affect animal responses are those involving the sudden and rapid onset of noise, and sources identified as important are helicopters, sonic booms, low flying aircraft, artillery/rockets, blasting/explosions, fireworks, motorboats and float planes, and for fish, intense underwater impulse noise.

The above thresholds are proposed as a screening process to determine whether more detailed study is necessary, on the understanding that even if the thresholds are not exceeded some 'slight' responses can still arise. The definition of the 'slight' criterion allows for the fact that under some circumstances animals can return to pre-exposure conditions relatively quickly and without continuing adverse effects.

The application of the proposed assessment methodology has been tested for two animal species (black grouse and golden plover) using data relating to a recent planning application for military development at the Otterburn Training Area in the Northumberland National Park. As intended, the process enables a much clearer picture of the likely interaction between a development's noise emissions and local animal populations to be presented, and also draws out those areas where there may be a potential for impacts and hence where mitigation measures or further study should be best applied.

The methodology has also been applied retrospectively to a wildlife park where exposure to noise from low-flying jet aircraft is known to have caused moderate and severe responses from certain animals. The conclusions and recommendations resulting from application of the proposed assessment methodology were consistent with the actual events that occurred following exposure to the noise.

Nevertheless, there are areas where the assessment procedure, or more particularly the information utilised within the assessment process, could be improved or made easier for prospective users. This principally involves the collection of further data as follows:

- An important element of the assessment is the relationship between the frequency characteristics of the noise source and the hearing sensitivity of each animal. This research has sought to provide as much information as possible to provide a database of animal hearing sensitivities against which the source noise can be compared. This database should be extended as and when detail becomes available for specific species not presently included within the list;

- A problem associated with the response data collected to date is that the noise units are often not quoted or are not presented using either common noise indices or the index most appropriate to the animal under study, i.e. having regard to its hearing sensitivity. For all future studies, it is recommended that all relevant noise data and source operating characteristics be reported, i.e. use of both linear and A-weighted measurements, covering at least the L_{Aeq} and L_{Amax} indices, with frequency analysis, coupled with source operating parameters such as distance, height and speed etc. that will affect noise levels at the animal position.

- When assessing the likely effect of an absolute noise level on a particular animal, it would be helpful to know the range of noise levels that the species is routinely exposed to in its daily life. For example, animals such as birds that reside in large colonies are often exposed to high levels of noise from social 'calling'. The likelihood is that where the colony population is dense, noise levels will be particularly high. The sounds will generally also contain frequencies that fall within the animal's most sensitive hearing range since the latter is often linked to communication frequencies.

  The animal's activities might also generate high noise levels. For example, there is no information on noise levels caused directly at the ear or other hearing transducers as a consequence of flight, diving or swimming, especially when the animal may be travelling fast in a turbulent medium. Similar effects would be caused by high wind speeds either around the animal's head or over its place of abode.

- In the same way that an animal can generate noise, natural events can themselves generate high noise levels. Some of these effects have been touched upon in Chapter 4 but further data relating to noise due to storm conditions, earthquakes, glacial shelf movements, water currents etc. would help place man-made noises in better context.

- Nocturnal animals often rely more heavily upon their hearing than their eyesight, especially for detecting prey or avoiding predators. At the same time, ambient noise levels will generally be much lower at night-time, thereby allowing lower source noise levels to be audible. Therefore, intruding noise levels at night will have a greater potential for interacting with nocturnal animals than with other species during the daytime. The possibility of a night-time weighting, e.g. reducing the screening threshold by 10 dB at night-time, needs further investigation.

In contrast, nocturnal species that sleep during the day may experience less of an impact from sudden daytime noises because although an animal might be awakened, the very short event time might not enable the animal to become fully aware of the significance of what caused it to awaken. Further research is required to confirm this.

- Finally, many animals appear to have an ability to determine the degree of threat that a noise might pose, i.e. if viewed as an approaching predator, from the noise source's changing level, frequency content and signal acuity, which probably allows them to locate the direction of the source and determine its rate of progress towards them. In contrast, animals do not appear able to use complex helicopter noise in the same manner. Research into which elements of noise transmission are actively used by animals to determine its spatial and temporal separation from a noise source, and hence whether it should respond by flight or other physiological or behavioural actions, would enable a better understanding of likely responses for a given situation. The components within firework noises that cause disturbance and fright compared to other noise sources also require further analysis.

With regard to the discovered response of songbirds to ambient noise levels, exposure of individual caged birds to different source noise levels would enable specific matters such as the on and off thresholds and the absolute change capable of being produced by different individuals and species to be determined, along with the maximum increase that birds can produce, which can be used to determine source limits above which birds cannot compensate for potential loss of territory by louder singing.

In the case of the habituation of horses or other animals to explosive noises, the exposure of naive animals could be used to establish the number of exposures required until the response stabilises at its minimum. The latter could be achieved by filming individual animals to subsequently count the number of steps taken or the distance travelled between the initial startle response until the animal returns to normal grazing or the pre-exposure behaviour, and to repeat this over successive exposures to plot the rate of change to the response of physical movement.

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APPENDIX I

Descriptions of "Development" as defined by the Town and Country Planning (Environmental Impact Assessment) Regulations 1999[4]

SCHEDULE 1 **Regulation 2(1)**

DESCRIPTIONS OF DEVELOPMENT FOR THE PURPOSES OF THE DEFINITION OF "SCHEDULE I DEVELOPMENT"

Interpretation

In this Schedule -
"airport" means an airport which complies with the definition in the 1944 Chicago Convention setting up the International Civil Aviation Organisation (Annex 14)(a);
"express road" means a road which complies with the definition in the European Agreement on Main International Traffic Arteries of 15 November 1975(b);
"nuclear power station" and "other nuclear reactor" do not include an installation from the site of which all nuclear fuel and other radioactive contaminated materials have been permanently removed; and development for the purpose of dismantling or decommissioning a nuclear power station or other nuclear reactor shall not be treated as development of the description mentioned in paragraph 2(b) of this Schedule.

Descriptions of development

The carrying out of development to provide any of the following -

1. Crude-oil refineries (excluding undertakings manufacturing only lubricants from crude oil) and installations for the gasification and liquefaction of 500 tonnes or more of coal or bituminous shale per day.

2. (a) Thermal power stations and other combustion installations with a heat output of 300 megawatts or more; and
   (b) Nuclear power stations and other nuclear reactors (except research installations for the production and conversion of fissionable and fertile materials, whose maximum power does not exceed 1 kilowatt continuous thermal load).

3. (a) Installations for the reprocessing of irradiated nuclear fuel.
   (b) Installations designed-
      (i) for the production or enrichment of nuclear fuel,
      (ii) for the processing of irradiated nuclear fuel or high-level radioactive waste,
      (iii) for the final disposal of irradiated nuclear fuel,
      (iv) solely for the final disposal of radioactive waste,
      (v) solely for the storage (planned for more than 10 years) of irradiated nuclear fuels or radioactive waste in a different site than the production site.

4. (a) Integrated works for the initial smelting of cast-iron and steel;
   (b) Installations for the production of non-ferrous crude metals from ore, concentrates or secondary raw materials by metallurgical, chemical or electrolytic processes.

5. Installations for the extraction of asbestos and for the processing and transformation of asbestos and products containing asbestos -
   (a) for asbestos-cement products, with an annual production of more than 20,000 tonnes of finished products;
   (b) for friction material, with an annual production of more than 50 tonnes of finished products; and
   (c) for other uses of asbestos, utilisation of more than 200 tonnes per year.

6. Integrated chemical installations, that is to say, installations for the manufacture on an industrial scale of substances using chemical conversion processes, in which several units are juxtaposed and are functionally linked to one another and which are -
   (a) for the production of basic organic chemicals;
   (b) for the production of basic inorganic chemicals;
   (c) for the production of phosphorous-, nitrogen- or potassium-based fertilisers (simple or compound fertilisers);
   (d) for the production of basic plant health products and of biocides;
   (e) for the production of basic pharmaceutical products using a chemical or biological process;
   (f) for the production of explosives.

7. (a) Construction of lines for long-distance railway traffic and of airports with a basic runway length of 2,100 metres or more;
   (b) Constructlon of motorways and express roads;
   (c) Construction of a new road of four or more lanes, or realignment and/or widening of an existing road of two lanes or less so as to provide four or more lanes, where such new road, or realigned and/or widened section of road would be 10 kilometres or more in a continuous length.

8. (a) Inland waterways and ports for inland-waterway traffic which permit the passage of vessels of over 1,350 tonnes;
   (b) Trading ports, piers for loading and unloading connected to land and outside ports (excluding ferry piers) which can take vessels of over 1,350 tonnes.

9. Waste disposal installations for the incineration, chemical treatment (as defined in Annex IIA to Council Directive 75/442/EEC(a) under heading D9), or landfill of hazardous waste (that is to say, waste to which Council Directive 91/689/EEC(b) applies).

10. Waste disposal installations for the incineration or chemical treatment (as defined in Annex IIA to Council Directive 75/442/EEC under heading D9) of non-hazardous waste with a capacity exceeding 100 tonnes per day.

11. Groundwater abstraction or artificial groundwater recharge schemes where the annual volume of water abstracted or recharged is equivalent to or exceeds 10 million cubic metres.

12. (a) Works for the transfer of water resources, other than piped drinking water, between river basins where the transfer aims at preventing possible shortages of water and where the amount of water transferred exceeds 100 million cubic metres per year;
    (b) In all other cases, works for the transfer of water resources, other than piped drinking water, between river basins where the multi-annual average flow of the basin of abstraction exceeds 2,000 million cubic metres per year and where the amount of water transferred exceeds 5% of this flow.

13. Waste water treatment plants with a capacity exceeding 150,000 population equivalent as defined in Article 2 point (6) of Council Directive 91/271/EEC(c).

14. Extraction of petroleum and natural gas for commercial purposes where the amount extracted exceeds 500 tonnes per day in the case of petroleum and 500,000 cubic metres per day in the case of gas.

15. Dams and other installations designed for the holding back or permanent storage of water, where a new or additional amount of water held back or stored exceeds 10 million cubic metres.

16. Pipelines for the transport of gas, oil or chemicals with a diameter of more than 800 millimetres and a length of more than 40 kilometres.

17. Installations for the intensive rearing of poultry or pigs with more than-
    (a) 85,000 places for broilers or 60,000 places for hens;
    (b) 3,000 places for production pigs (over 30 kg); or
    (c) 900 places for sows.

18. Industrial plants for-
    (a) the production of pulp from timber or similar fibrous materials;
    (b) the production of paper and board with a production capacity exceeding 200 tonnes per day.

19. Quarries and open-cast mining where the surface of the site exceeds 25 hectares, or peat extraction where the surface of the site exceeds 150 hectares.

20. Installations for storage of petroleum, petrochemical or chemical products with a capacity of 200,000 tonnes or more.

SCHEDULE 2 **Regulation 2(1)**

DESCRIPTIONS OF DEVELOPMENT AND APPLICABLE THRESHOLDS AND CRITERIA FOR THE PURPOSES OF THE DEFINITION OF "SCHEDULE 2 DEVELOPMENT"

1. In the table below -
"area of the works" includes any area occupied by apparatus, equipment, machinery, materials, plant, spoil heaps or other facilities or stores required for construction or installation;
"controlled waters" has the same meaning as in the Water Resources Act 1991(a);
"floorspace" means the floorspace in a building or buildings.

2. The table below sets out the descriptions of development and applicable thresholds and criteria for the purpose of classifying development as Schedule 2 development.

TABLE

Column 1 *Description of development*	*Column 2* *Applicable thresholds and criteria*
The carrying out of development to provide any of the following-	
1. *Agriculture and aquaculture*	
(a) Projects for the use of uncultivated land or semi-natural areas for intensive agricultural purposes;	The area of the development exceeds *0.5* hectare.
(b) Water management projects for agriculture, including irrigation and land drainage projects;	The area of the works exceeds I hectare.
(c) Intensive livestock installations (unless included in Schedule 1);	The area of new floorspace exceeds 500 square metres.
(d) Intensive fish farming;	The installation resulting from the development is designed to produce more than 10 tonnes of dead weight fish per year.
(e) Reclamation of land from the sea.	All development.

2. *Extractive industry*	
(a) Quarries, open-cast mining and peat extraction (unless included in Schedule 1);	All development except the construction of buildings or other ancillary structures where the new floorspace does not exceed 1,000 square metres.
(b) Underground mining;	
(c) Extraction of minerals by fluvial dredging;	All development.
(d) Deep drillings, in particular- (i) geothermal drilling; (ii) drilling for the storage of nuclear waste material; (iii) drilling for water supplies; with the exception of drillings for investigating the stability of the soil.	(i) In relation to any type of drilling, the area of the works exceeds 1 hectare; or (ji) in relation to geothermal drilling and drilling for the storage of nuclear waste material, the drilling is within 100 metres of any controlled waters.
(e) Surface industrial installations for the extraction of coal, petroleum, natural gas and ores, as well as bituminous shale.	The area of the development exceeds 0.5 hectare.

3. Energy industry	
(a) Industrial installations for the production of electricity, steam and hot water (unless included in Schedule I);	The area of the development exceeds 0.5 hectare.
(b) Industrial installations for carrying gas, steam and hot water;	The area of the works exceeds I hectare.
(c) Surface storage of natural gas; (d) Underground storage of combustible gases; (e) Surface storage of fossil fuels;	(i) The area of any new building, deposit or structure exceeds 500 square metres; or (ii) a new building, deposit or structure is to be sited within 100 metres of any controlled waters.
(f) Industrial briquetting of coal and lignite;	The area of new floorspace exceeds 1,000 square metres.
(g) Installations for the processing and storage of radioactive waste (unless included in Schedule 1);	(i) The area of new floorspace exceeds 1,000 square metres; or (ii) the installation resulting from the development will require an authorisation or the variation of an authorisation under the Radioactive Substances Act 1993.
(h) Installations for hydroelectric energy production;	The installation is designed to produce more than 0.5 megawatts.
(i) Installations for the harnessing of wind power for energy production (wind farms).	(i) The development involves the installation of more than 2 turbines; or (ii) the hub height of any turbine or height of any other structure exceeds 15 metres.

4. Production and processing of metals	
(a) Installations for the production of pig iron or steel (primary or secondary fusion) including continuous casting; (b) Installations for the processing of ferrous metals- (i) hot-rolling mills; (ii) smitheries with hammers; (iii) application of protective fused metal coats. (c) Ferrous metal foundries; (d) Installations for the smelting, including the alloyage, of non-ferrous metals, excluding precious metals, including recovered products (refining, foundry casting, etc.); (e) Installations for surface treatment of metals and plastic materials using an electrolytic or chemical process; (f) Manufacture and assembly of motor vehicles and manufacture of motor-vehicle engines; (g) Shipyards; (h) Installations for the construction and repair of aircraft; (i) Manufacture of railway equipment; (j) Swaging by explosives; (k) Installations for the roasting and sintering of metallic ores.	The area of new floorspace exceeds 1,000 square metres.

5. Mineral industry	
(a) Coke ovens (dry coal distillation); (b) Installations for the manufacture of cement; (c) Installations for the production of asbestos and the manufacture of asbestos-based products (unless included in Schedule 1); (d) Installations for the manufacture of glass including glass fibre; (e) Installations for smelting mineral substances including the production of mineral fibres; (f) Manufacture of ceramic products by burning, in particular roofing tiles, bricks, refractory bricks, tiles, stonewear or porcelain.	The area of new floorspace exceeds 1,000 square metres.

6. Chemical industry (unless included in Schedule 1)	
(a) Treatment of intermediate products and production of chemicals; (b) Production of pesticides and pharmaceutical products, paint and varnishes, elastomers and peroxides;	The area of new floorspace exceeds 1,000 square metres.
(c) Storage facilities for petroleum, petrochemical and chemical products.	(ii) The area of any new building or structure exceeds 0.05 hectare; or (ii) more than 200 tonnes of petroleum, petrochemical or chemical products is to be stored at any one time.

7. Food industry	
(a) Manufacture of vegetable and animal oils and fats; (b) Packing and canning of animal and vegetable products; (c) Manufacture of dairy products; (d) Brewing and malting; (e) Confectionery and syrup manufacture; (f) Installations for the slaughter of animals; (g) Industrial starch manufacturing installations; (h) Fish-meal and fish-oil factories; (i) Sugar factories	The area of new floorspace exceeds 1,000 square metres.

8. Textile, leather, wood and paper industries.	
(a) Industrial plants for the production of paper and board (unless included in Schedule I); (b) Plants for the pre-treatment (operations such as washing, bleaching, mercerisation) or dyeing of fibres or textiles; (c) Plants for the tanning of hides and skins; (d) Cellulose-processing and production installations.	The area of new floorspace exceeds 1,000 square metres.

9. Rubber industry	
Manufacture and treatment of elastomer-based products.	The area of new floorspace exceeds 1,000 square metres.

10. *Infrastructure projects*	
(a) Industrial estate development projects;I (b) Urban development projects, including the construction of shopping centres and car parks, sports stadiums, leisure centres and multiplex cinemas; (c) Construction of intermodal transshipment facilities and of intermodal terminals (unless included in Schedule 1);	The area of the development exceeds 0.5 hectare.
(d) Construction of railways (unless included in Schedule 1);	The area of the works exceeds 1 hectare.
(e) Construction of airfields (unless included in Schedule 1);	(i) The development involves an extension to a runway; or (ii) the area of the works exceeds 1 hectare.
(f) Construction of roads (unless included in Schedule 1);	The area of the works exceeds 1 hectare.
(g) Construction of harbours and port installations including fishing harbours (unless included in Schedule 1);	The area of the works exceeds 1 hectare.
(h) Inland-waterway construction not included in Schedule 1, canalisation and flood-relief works; (i) Dams and other installations designed to hold water or store it on a long-term basis (unless included in Schedule I); (j) Tramways, elevated and underground railways, suspended lines or similar lines of a particular type, used exclusively or mainly for passenger transport;	The area of the works exceeds 1 hectare.
(k) Oil and gas pipeline installations (unless included in Schedule 1); (l) Installations of long-distance aqueducts;	(i) The area of the works exceeds 1 hectare; or, (ii) in the case of a gas pipeline, the installation has a design operating pressure exceeding 7 bar gauge.
(m) Coastal work to combat erosion and maritime works capable of altering the coast through the construction, for example, of dykes, moles, jetties and other sea defence works, excluding the maintenance and reconstruction of such works;	All development.
(n) Groundwater abstraction and artificial groundwater recharge schemes not included in Schedule 1; (o) Works for the transfer of water resources between river basins not included in Schedule 1;	The area of the works exceeds 1 hectare.
(p) Motorway service areas.	The area of the development exceeds 0.5 hectare.

11. Other projects	
(a) Permanent racing and test tracks for motorised vehicles;	The area of the development exceeds 1 hectare.
(b) Installations for the disposal of waste (unless included in Schedule 1);	(i) The disposal is by incineration; or (ii) the area of the development exceeds 0.5 hectare; or (iji) the installation is to be sited within 100 metres of any controlled waters.
(c) Waste-water treatment plants (unless included in Schedule 1);	The area of the development exceeds 1,000 square metres.
(d) Sludge-deposition sites; (e) Storage of scrap iron, including scrap vehicles;	(i) The area of deposit or storage exceeds 0.5 hectare; or (ii) a deposit is to be made or scrap stored within 100 metres of any controlled waters.
(f) Test benches for engines, turbines or reactors; (g) Installations for the manufacture of artificial mineral fibres; (h) Installations for the recovery or destruction of explosive substances; (i) Knackers' yards.	The area of new floorspace exceeds 1,000 square metres.

12. *Tourism and leisure*	
(a) Ski-runs, ski-lifts and cable-cars and associated developments;	(i) The area of the works exceeds 1 hectare; or (ji) the height of any building or other structure exceeds 15 metres.
(b) Marinas;	The area of the enclosed water surface exceeds 1,000 square metres.
(c) Holiday villages and hotel complexes outside urban areas and associated developments; (d) Theme parks;	The area of the development exceeds 0.5 hectare.
(e) Permanent camp sites and caravan sites;	The area of the development exceeds 1 hectare.
(f) Golf courses and associated developments.	The area of the development exceeds 1 hectare.

13.	
(a) Any change to or extension of development of a description listed in Schedule 1 or in paragraphs 1 to 12 of Column 1 of this table, where that development is already authorised, executed or in the process of being executed, and the change or extension may have significant adverse effects on the environment;	(i) In relation to development of a description mentioned in Column 1 of this table, the thresholds and criteria in the corresponding part of Column 2 of this table applied to the change or extension (and not to the development as changed or extended) (ii) In relation to development of a description mentioned in a paragraph in Schedule 1 indicated below, the thresholds and criteria in Column 2 of the paragraph of this table indicated below applied to the change or extension (and not to the development as changed or extended): *Paragraph in Schedule I* — *Paragraph of this table* 1 — 6(a) 2(a) — 3(a) 2(0) — 3(g) 3 — 3(g) 4 — 4 5 — 5 6 — 6(a) 7(a) — 10(d) (in relation to railways) or 10(e) (in relation to airports) 7(b) and (c) — 10(f) 8(a) — 10(h) 8(b) — 10(g) 9 — 11(b) 10 — 11(b) 11 — 10(n) 12 — 10(o) 13 — 11(c) 14 — 2(e) 15 — 10(i) 16 — 10(k) 17 — 1(c) 18 — 8(a) 19 — 2(a) 20 — 6(c)
(b) Development of a description mentioned in Schedule 1 undertaken exclusively or mainly for the development and testing of new methods or products and not used for more than two years.	All development.

APPENDIX IV

Effects of Noise on Animals - The Marine Environment

EFFECTS OF NOISE ON ANIMALS - THE MARINE ENVIRONMENT

Low frequency sonar systems are being increasingly used within the marine environment for detection purposes as well as general environment monitoring, e.g. temperature change. In 1999 the US Navy prepared an Environmental Impact Statement[408] with respect to their proposed use of the Surveillance Towed Array Sensor System (SURTASS) Low Frequency Active (LFA) sonar throughout the world's oceans. Due to the very quiet operations of modern submarines, the new sonar is aimed at increasing detection distances through the use of a long range low frequency signal between 100 and 500 Hz. The active part of the system produces the sonar signal or 'ping' lasting between 6 to 100 seconds, with the interval between being from 6 to 15 minutes. Information on the sound levels at or close to the source were not apparent within the EIA (other than a statement that "the signals are loud at the source, but levels diminish rapidly over the first kilometre."), although the limiting factor on the sonar's use is defined as to prevent exposure of 180 dB within 22 km (12 nautical miles) of land.

The EIA initially undertook a literature review to identify sensitive marine species and concluded that the large baleen whales were the animals most likely to be affected by LF sound due to their hearing sensitivity within LFA sonar frequency band. An exposure standard referred to by the EIA as most recently accepted by the marine bioacoustic community is a received level (RL) of 140 dB at which level most marine mammals actively avoid the area of the source. However, studies undertaken by the Low Frequency Sound Scientific Research Program (LFS SRP) report that animals exposed to RLs up to 155 dB were not seen to respond, or exhibited only temporary behavioural response with no lasting biological significance, such as brief cessation of vocalisation by some humpback whales and resumption of normal behaviour within ten or so minutes.

References to underwater sound pressure levels are typically quoted as dB standardised at 1µPa at 1m (dB re 1µPa at 1m) for source levels (SL) and dB re 1µPa rms (root mean squared) for received levels (RL).

In order to evaluate the biological risk for marine mammals, exposure criteria were developed to encompass the RL levels, length of the individual signal or 'ping', and total number of pings received. The result is a unit of measure referred to as the Single Ping Equivalent (SPE), which aims to take account of the variation of risk with repeated exposure and the variation due to actual RL level. Following the studies of the LFS SRP it is postulated that the risk threshold is lowered by 5 dB for every tenfold increase in the number of sounds in the exposure, which produces the following equation for the derivation of the SPE:

SPE	=	$L + 5 \log_{10}(N)$
Where L	=	received level (RL) in decibels
N	=	number of exposures

On this basis, 100 pings at 170 dB would be equivalent to one ping at 180 dB.

The full results of the LFS SRP indicated that using the above risk function as a measure of the risk of non-injurious harassment, at levels below 120 dB the risk was zero; for an SPE of 150 dB the risk was 2.5%; at 180 dB the risk was 95%; and above

180 dB the risk approached 100%. Non-injurious harassment is considered by the EIA to be an injury from which a marine mammal would recover, e.g. TTS.

The EIA applied an initial screening to determine marine animal species that could potentially be affected by the LF sonar. To be affected, animals must be within the geographic area of the noise source and its transmitted signal, and also capable of being physically affected by the sound, i.e. to have its hearing affected in some way. From these criteria it is evident that the assessment did not consider the physiological responses and the secondary responses that could arise as a consequence of interruption of, for example, feeding processes or predator-prey relationships. Virtually all invertebrates were eliminated from further assessment because they do not have delicate organs or tissues whose acoustic impedance is significantly different from water, and there is no evidence of auditory capability in the frequency range used by SURTASS LFA sonar. The remaining invertebrates, cephalopods and decapods were eliminated by virtue of their high hearing thresholds in the LF range. As a consequence the screening process reduced the list of animals to be studied to six groups of vertebrates, namely sharks and rays, bony fishes, whales, dolphins, seals and sea lions, and sea turtles.

The next stage in the EIA was to determine the population distribution, abundance, density, general movement and diving profile data for the potentially affected species and to enter this into an Acoustic Integration Model to simulate the acoustic exposure for each animal for each sonar ping during a hypothetical SURTASS LFA mission. With respect to potential effects on fish, including sharks and some prey species for marine animals, the assessment concluded that the use of SURTASS LFA sonar systems would not be significant for several reasons that included the small number of sonar systems deployed, slow moving base ships compared to the speed of animals, the low probability of substantial fish stocks within the 180 dB field, and the small percentage of fish stocks that could potentially be affected compared to the entire stocks within the oceans.

Since most turtles reside within coastal areas, the EIA conclusions were that there would be a very low probability of serious injury for the same sort of reasons that applied to fish. The overall conclusions of the assessment were that operation of the sonar could result in the remote possibility of injury to fish and sea turtles, and non-serious injury and non-injurious harassment of marine mammals. Although no non-serious injuries were predicted, any 'taking' would be infrequent, unavoidable, or accidental, and the numbers taken would be so small as to have a negligible impact on the affected species' stocks and upon the availability of the species for subsistence needs. On this basis, it is evident that the proposed sonar is considered to have lethal implications for individuals of a species that may be present within the zone of greatest effect, i.e. within the area equivalent to SPEs greater than 180 dB, but that any loss is not considered to be significant with respect to the ocean's overall stocks of each species. The area likely to experience RLs>180 dB is identified as a 1 km radius disc, approximately 65m in depth, centred upon the sound transmitters.

In order to monitor global warming using the Acoustic Thermometry of Ocean Climate (ATOC), sound sources have been deployed approximately 10 km off the coast of Kauai, Hawaii, and approximately 90 km off the coast of San Francisco, California. The sound sources are at a depth of approximately 3,000 feet (900m), which corresponds to deep ocean channels, created by the variation of pressure and temperature with depth, that are capable of transmitting sound over very long distances. Low frequency sound signals are transmitted intermittently and detected thousands of miles away by a network of underwater hydrophones located throughout the Pacific Ocean. The change in signal travel time between the sound source and the hydrophone enables the average sea temperature to be determined. The system is capable of detecting variations as small as 20 milliseconds in the hour-long time it takes signals to travel 3,000 miles (4,800 km), which allows the average ocean temperature to be calculated to within 0.006°C.

As part of the early ATOC research program, the US Heard Island Feasibility Test transmitted signals of 209-220 dB re 1μPa tones centred on 57 Hz at a depth of 175 m and monitored the effects on the density and behaviour of marine mammals within a 70 km square centred 60 km southeast of Heard Island[409]. Forty schools of cetaceans and 19 pinnipeds were sighted before the transmission and 40 schools and 25 pinnipeds were sighted after. Schools of hourglass dolphins (*Lagenorhynchus cruciger*) increased and schools of mid-sized whales, mainly southern bottlenose whales (*Hyperoodon planifrons*) and minke whales (*B. acutorostrata*), decreased, with no obvious cause for these changes being observed and no consistent changes in direction of travel.

Comparison of the behaviour of endangered whales before and during transmissions showed changes in respiration and reorientation rates, but whales were still able to navigate, interact with each other and continue to lunge-feed during transmission. Although the signal was observed to cause some physiological responses, the overall observations suggest no undue adverse effects. However, it is interesting to note that whereas calls of sperm whales (*Physeter macrocephalus*) and pilot whales were detected for 22% of the 123 hours surveyed prior to the transmission, they were not detected during the 7 day transmission period and were detected again within 2 days of the transmission ceasing. This suggests that at least for some species there is a possibility that such signals have an undesirable effect for whatever reason, causing animals to move away. However, there was no information on actual levels within and outside the study area to be able to tell whether conditions were significantly different in terms of noise level or perhaps feeding conditions.

Marine Mammal Research Programs (MMRP) have been undertaken annually in the vicinity of the ATOC sound sources in order to identify any adverse impacts on marine mammal populations. The overall conclusion of the research to date is that no acute or short-term effects have been observed and no MMRP results indicate that any species show any biologically significant adverse response to the ATOC sound output[410]. The Hawaiian Islands in particular are a calving and breeding site for Humpback whales each year between the months of December and May, and the results of the MMRP studies for this location can be summarised as follows:

- The ATOC sound level in the near shore waters where 74% of the humpbacks are found is low (85-115 dB re 1μPa, 60-90 Hz);
- The ATOC transmissions did not affect the sighting rate or the actual numbers of whales;
- There was no statistically significant change in behaviour during the transmissions;
- The distance between successive surfacings for an individual whale increased with increasing estimated sound level at a rate of 26m per 1 dB. However, whilst the effect appears real and statistically significant, the MMRP interpreted the biological significance as being relatively small;

- No differences were detected in the acoustic power level for a frequency band containing humpback song, which suggests that ATOC transmissions do not affect the total acoustic output of humpback 'singers'; and
- Aerial surveys for 1993, 1994, 1995 and 1998 revealed no statistically significant difference in whale distance from the source between the year with ATOC transmissions and the years without.

It may be relevant that the MMRP analysed the humpback song in terms of total sound power output per frequency band rather than changes to the song content itself. Other researchers have reported that male humpback whales lengthen their songs when exposed to low-frequency sonar signals. In response to 10 42-second low-frequency sonar signals transmitted at 6-minute intervals to 16 humpback whales during the breeding season, male songs were on average 29% longer during sonar transmissions. The precise reason for this change is unknown but the song may simply be longer to compensate for the noise of the sonar. A typical noise level generated by the song of the humpback male would be 170 dB re 1μPa, which it can be seen is higher than the ATOC levels of 85-115 dB reported for the waters occupied by humpbacks off Hawaii but lower than the ATOC source levels of 209-220 dB.

Other studies of the humpbacks off the Australian coast analysed the song content between 1995 and 1998. In 1995 and 1996, 2 out of 82 humpback whales on the east coast were heard to be singing a new song, which was similar to the tunes sung by whales on the west coast. By the end of the 1997 southward migration almost all whales had switched songs, and in 1998 only the new song was heard, which had no similarity in structure to the old. The researchers propose that the change in song may reflect a 'novelty' factor in the males' competition for females. Clearly, as with all courtship displays, the humpback male's performance in song will be important in securing a mate, however, it seems too coincidental to expect an evolutionary trend such as the song change to occur just at the time of the study, especially since such changes would normally be a slow process of many years to enable natural selection to work. It seems more probable that the change was initiated by other outside factors, and perhaps the effects of low-frequency transmissions within the ocean need further investigation.

In the case of human divers, the presence of low frequency sounds will provoke a temporary decrease in heart rate that is consistent with a normal non-habituating orienting response to sound[411] (in contrast to many animal responses to noise where the heart rate has increased), and can also produce variable 'aversion' responses. For frequencies below 100 Hz, vibration and resonance of anatomical structures/organs are the dominant factors influencing the aversion response[412]. It would seem logical to conclude that a similar response is likely within some marine mammals, which would explain why some species were noticeably absent or declined in numbers during observations made during the ATOC transmissions.

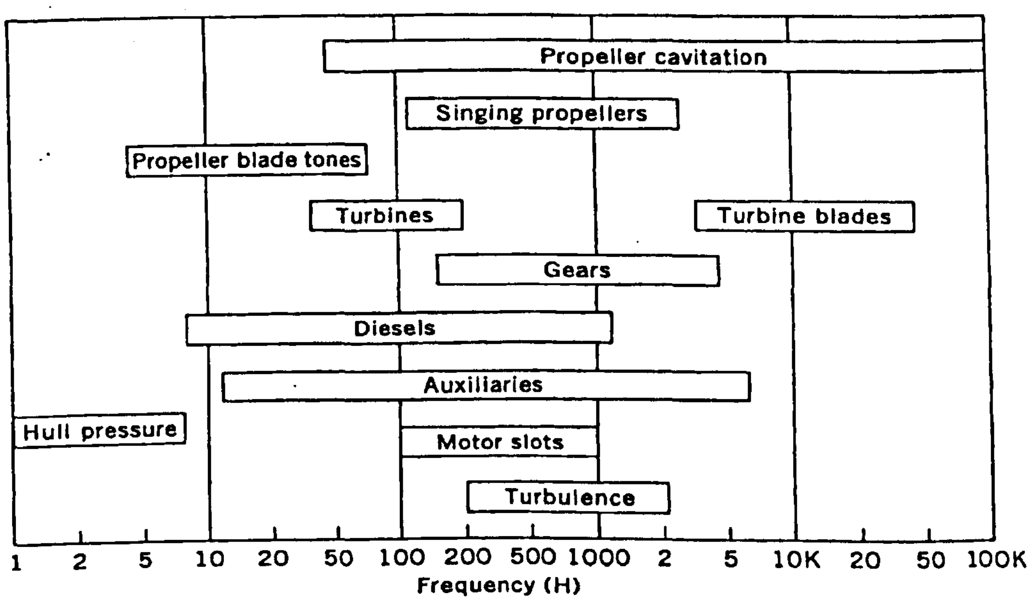
Furthermore, accidental and experimental exposure of divers to high levels of low frequency noise have resulted in transient neurological symptoms[413], and again the possibility exists that some marine mammals might be similarly disorientated. The physiological effects reported by one diver were light-headedness, dizziness, lethargy, vibration in the extremities and blurring of vision, and in another, the sensation of vibration affecting the brain and teeth, and a sensitivity to noise accompanied by increased irritability and inability to concentrate several weeks after the exposure. Experimental surveys showed that low frequency sounds cause the human skull to vibrate at frequencies between 50-1250 Hz, with maximum displacement occurring between 500-900 Hz. At the present time, there is insufficient evidence to establish to what extent such displacement magnitudes might cause neurological damage. However, whatever the eventual findings, it is likely that similar responses can be expected within skulls and brains of marine mammals exposed to high levels of low frequency sound.

A further Environmental Impact Statement has been prepared by the US Office of Naval Research for the continued operation for five additional years of the ATOC sound source off Hawaii[414]. Of the possible effects on marine life - physical auditory effects, behavioural disruption, habituation, masking, long term effects, and indirect effects - only the physical auditory effects and behavioural disruption are considered to be of any significance. The assessment refers to the MMRP findings discussed above and concludes that although there were some subtle changes in the distance and time between successive humpback whale surfacings during transmission periods, and in the distribution of whales away from the source, these effects would not adversely affect the survival of an individual whale or the status of the North Pacific humpback whale population.

In terms of noise exposures using the SPE noise index, a risk continuum developed as part of the assessment estimated that 95% of marine mammals exposed to an SPE of 180 dB could experience a temporary threshold shift (TTS); that the risk of disturbing a biologically important behaviour is zero below 120 dB; and that 2.5% of a population exposed to an SPE of 150 dB would experience disturbance of a biologically important behaviour.

Hearing becomes more useful than sight for animals underwater, and, since sounds in water can travel with little energy loss over very great distances (hundreds or thousands of miles in the case of some low frequencies), many activities on or under water, e.g. ship's engines, have the potential to affect large areas of ocean and marine life. An indication of the frequency ranges of noise radiated by the various engine components likely to be associated with ships and their movement in the oceans is shown in Figure A4.1. With regard to the routine propulsive sources of noise, it is considered that there are unlikely to be significant differences between military and civilian sources because the basic mechanical operations will be identical for a given class of vehicle.

Figure A4.1: Frequency Ranges of Noise Emitted by Shipping



Recent studies into noise levels within the oceans have enabled noise levels associated with common man-made activities to be quantified and hence compared with levels from animal activities and from natural events. Noise levels in dB re 1 μPa at a reference distance of 1 metre are presented in Table A4.1. Of the man-made noises, underwater explosions represent the highest noise level by far at 270 dB or more re 1 μPa at 1m, followed by activities such as ATOC and LFA sonar at between 195-235 dB, with shipping noise levels ranging from 165-190 dB. However, with the exception of noise levels from explosions, marine mammal calls and movements generate similar levels of noise ranging from 130-230 dB, albeit of much shorter durations.

Table A4.1: Source noise levels (dB re 1 μPa at 1m) for various man-made, mammalian and natural sources of underwater noise

Source	dB re 1 μPa at 1m	Comments
Man-made:		
Explosions	270+	Transient and localised, near-shore construction projects
Low frequency sonar	235	Cyclical low frequency 'pings'
Seismic oil exploration	210	Transient low frequency pulses in oil-rich areas of oceans
ATOC research	195	Low frequency sound pulses from two sources transmitted along various pathways through the Pacific Ocean
Ice breakers	185-190	Transient, primarily in Arctic Ocean, north of Canada, Alaska and Russia
Supertanker	~ 187	Continuous noise present on all shipping routes
Large tanker	175-185	Continuous noise present on all shipping routes
Drilling ships	175-185	Continuous and intermittent noises at specific locations
Merchant ships	~ 175	Continuous noise present on all shipping routes
Dredging	165-185	Transient and localised, near-shore
Marine mammal sounds: Calls and whistles		
Humpback whale	Up to 190	Fluke/flipper slaps: 183-192 dB
Bowhead whale	Up to 189	
Blue whale	~ 188	
Right whale	Up to 187	
Grey whale	~ 185	
Pilot whale	180	
Bearded seal	178	
Sperm whale	160-180	
Killer whale	160	Pulsed calls
Weddell seal	153-193	
Harp seal	130-140	
Bottlenose dolphin	125-173	
Sonar clicks		
False killer whale	220-228	
Bottlenose dolphin	218-228	
Beluga whale	206-225	
Killer whale	180	
Natural ocean sounds:		
Earthquake	95-135	
Wind and waves	~ 85	

APPENDIX V

Animal Audiogram Data

Amphibia/Reptiles:

Hearing Thresholds, dB re 20 µPa					
Hz	Bullfrog (mean)[248]	Green tree frog (mean)[248]	Grass frog (male) (mean)[415]	Grass frog (female) (mean)[415]	Red-eared turtle[416]
16					65
63					30
100	59.5	48.4	91	89	14
200	42.5		89	88	0
315	41.8	51.8	90	91	
400	19.7		89	90	
500			87	88	2
630	9.1	32.9	83	83	
700			83	82	12
800	16.8		83	81	
900		23.9	79	73	
1000			77	72	50
1200	17.6	42.9	71	68	
1600	19.9	40.8	81	78	
2000	40.2		76	75	
2600		55.1			
3000	74.7	39.9			
3500		52.3			
3800		57.2			
5000		69.3			

Birds: Hearing Thresholds, dB re 20 μPa

Hz	Budgerigar [265]	Canary (mean) [417,418,265,419]	Sparrow (mean) [420,265,421]	Parakeet (mean) [422,265,423,424,425]	Pigeon [416]	Pigeon [110]	Starling (mean) [426,427]	Redwing blackbird [428]	Crow [264]	Sparrowhawk [264]	Bluejay [429]	Cockatiel [265]	Barn owl [430]	Chicken [431]	Turkey [432]	Pheasant [433]	Mallard duck [264]
16						55											
25						47											
80						37											
100						32											
125						32	39	65						51			
200	50			50	30	47.8							24	42.5			
250		60.8	41.9	36.2		30	36.2	48			43	32				11	
315	40			29		36	25		39	38							45.5
400	32			25.3		12	53.2						8				
500	28	50.8	27.6	19.5	13	20.7	24.5	34		27	38	23		38.8	32	16	
630	25			16.5		16	28.5										
700	18	32		10		10											
800	16			11		10	23										
900	12																
1000	10	36	16.4	10.1	2	14.6	17.75	23	-17	8	19.5	17.5	-8	26	17	14	24.7
2000	3	28.5	8.4	6.1	7	18.8	6	12.5		7	11.5	8	-17.5	24	18	10	14.5
3000	3	30	8.4	3.5		16.8	5	16.5	-9.5			6	-12				20
4000	8	39.5	9.4	7.9	13	17.5	16.3	16.5		17.5	23.5	21.5	-18.5	37	31.5	7	
5000	17			12.3	20	33.3			18			47	-15.5				40
6000	20	48.3	15.7	22	53	62.2	31.8	20					-18				
7000	35			42.5	67	71.4	38		59	50.5			-15		71.5		75.5
8000	40	64	20.9	66.5	71	73.5	60.5	33	71	77	61	75	-10			9	83
9000	60		34.9			76	65.5									10	
10000	85		53.9			77	79.3	67			82.5		-6			8	
12000			64.8										35				

Mammals: Hearing Thresholds, dB re 20 μPa

Hz	Human (mean) [228]	Dog (mean) [276,277]	Chinchilla [416]	Guinea pig [416]	Gerbil [416]	Chimpanzee [434]	Macaque monkey (mean) [228]	Squirrel monkey (mean) [435,436,437]	Marmoset [438]	Lemur [439]	Hedgehog [440]	Opossum [441]	Sheep [442]	Horse [280]	Cattle [280]	Indian elephant [284]	Cat (mean) [271, 272,273 ,274 ,275 ,443]	Weasel [270]	Raccoon [444]	Ferret [445]	Rat (mean) [446,447,448,449,450, 269 ,451]	Kangaroo rat [452,268]	Mouse (mean) [42,453,454,268 ,455]	Rabbit [268,456,457]
16	82			62	40		72								71	64								
25							63									52		78		83				
32	58						57							80	55	43		66		65				
40		59															75					55		
50		65.5		52.5																				
63	36	59.9	44	50			36	45.2						55	42	38	48.7	55		43		53		70
80		50.7																						
100		44.3	22.7		34.5				41.2	49			60				36		41					
125	17	39.3	19	41.2		20	19	41.2						44	32	36	31.2	43		38		21.3		54
200		31.7	14.4						30.8	36			55				22.5		14					
250	10	26.2	11.8	34.8		10.5	15	27			69			26	21	24	16.9	30		30	72	16.3		40
315		22.7	10.4		25.5				19.1				34				11.9		9					
400		19.6																						
500	10	16.5	4.9	28.3	18.5	3.5	6	15.5	12.7	19	62.5	71		14	11	23.5	5.3	17	4	24	63.7	10.3		42
630		13.4	3.4																					
700		11.8	3.7	20.5					4.1				20				-1.4							
800		10.2																						
900		9.1																						
1000	-4	7.5	2	18.2	7	-5	4	8.7	4.2	6	47	60	22	8	6	8	-4.9	0	-15	12	39.5	9.3	72	25.5
2000	-10	1.8	3.3	13.2	1.7	-10	5	7.6	0.3	6	32	31		7	-1.5	18	-11.9	-9		18	38.1	10	61.7	21.4
3000		-1.1	2.5	6					11.2				12				-12.8		-10		24.7		36	
4000	-10	-1.9	1.3	8	1.9	-2	1	8	18.2	7	13.5	21		16	-7	23	-10	3		14	31.6	17	25.8	16.4
5000		-1.9			2.2				19.9				21				-16.8		-8		34		31.2	
6000		-1.4	6.4	1.5																13	25			-3.5

Hz	Human	Dog	Chinchilla	Guinea pig	Gerbil	Chimpanzee	Macaque monkey	Squirrel monkey	Marmoset	Lemur	Hedgehog	Opossum	Sheep	Horse	Cattle	Indian elephant	Cat	Weasel	Raccoon	Ferret	Rat	Kangaroo rat	Mouse	Rabbit
7000		-1.1		-0.5	3.9				-9				5				-15.2		-10		35			
8000	9	-0.9	9.3	-1.1	4.2	-8	5	4.8		1	4	29		10	-11	42	-11.1	3		4	20.8	17.1	18.5	4.8
9000		0.9																			33			
10000		3	10.5	-2.7	7			-3	1.5				-12			56	-11.7		-14	3	29		19.5	
16000							3																	
20000	91	10.2	21.4	11.1	10.4	80		16	41.8				-2						-1		30.3		11.5	
30000		23.3	53	18.8	14.8		39	16.8	53.5	14	17	21	8	47	42		5.4	8	18	28	11	36	29	24.3
40000		43.2		27.1	21		89	47		27			32	42	89				33		8		52.5	21.5
45000		62.3		38.3				82			37							12		60	16			48
50000		70		58.3	38.5					49							13				26		18	64
60000					64.5					62		50					33	68				70	37	
70000										86														
80000																							67.5	
90000																	80						57	
100000																							67.5	

Bats:

Hearing Thresholds, dB re 20 μPa					
Hz	Horseshoe bat[416]	Greater horseshoe bat[458]	Big brown bat[459]	Little brown bat[459]	Fish catching bat[460]
2000	100	92			
2500			89		
3000					
4000					
4500			52		
5000	62	54			
10000	30	28	12	61	
20000	1	-3	6	16	
22000					17.7
30000	8	2	2		5.7
40000	27	23	33	10	4.5
45000		20	32	19	
48000					6.5
50000	18	12	19	22	
60000	1	-3	10	15	24.5
70000	8	7	16	26	
80000	30	28	29	23	36.3
81000		4			
81500		-4			
85000		10			
90000	27	27	41	21	
95000					36.8
100000	60	57	70	29	65

Fish:

Hearing Thresholds, dB re 1 µPa						
Hz	Salmon[288]	Cod[288]	Skate[461]	Tuna[462,463]	Goldfish [464,465]	Minnow[466]
50	120			120	75	
63	115	108		128	74	
80	105	73		123	72	
100	98	68	125	122	70	
200	97	68	122	98	59	
315	108	70	128	94	57	81
400	112	72	132	90	56	83
500	120	75	134	88	55	85
630	125	100	135	92	55.5	83
700		108	137	97	56	81
800			143	100	57	80
900			145	110	57.5	78
1000				120	58	76
2000					100	87
3000					120	105
4000						117

Marine Mammals in Water:

Hz	Hearing Thresholds, dB re 1 µPa					
	Harbour seal[467,468]	Harbour porpoise[287,288]	Bottlenose dolphin[289]	Killer whale[285,286]	Manatee[469]	Human diver[469]
80	102					
100	97		125			102
200	83		122			95
315	83.5		118		102	88
400	84		115		103	82
500	83		110		90	77
630	82		105		83	76
700	81		100		82	75
800	80		95	98	80	74
900	78		92	100	77	74
1000	76	80	87	110	75	74
2000	73	78	83	108	70	75
3000	71	72	80	100	65	78
4000	70	65	77	93	60	80
5000	65	60	72	88	57	81
6000	63	55	69	80	55	82
7000	64	50	65	74	54	82.5
8000	65	48	60	62	53	83
9000	66	44	56	48	52	84
10000	66	45	54	40	51	85
20000	66	45	52	35	48	120
30000	68	45	49	38	77	
40000	70	45	48	38	100	
50000	71	44	47	44	110	
60000	98	45	48	74		
70000	110	50	52	80		
80000	115	54	55			
90000	120	57	61			
100000		60				

Marine Mammals in Air:

Hearing Thresholds, dB re 20 µPa					
Hz	Harbour seal[470]	Sea lion[471]	Harp seal[472]	Northern fur seal[473]	Northern elephant seal[473]
100					78
200					71
400					69
500				28	
800					57
1000	36		33	29.5	
2000	19		33	10	52
4000	26	31	29	23	
7000					43
8000	19	35.5	38	13	
9000					44
11250	16		35		
16000	26	37	41	10	52
20000					50
22500	58		41		59
24000		37.5		23	
28000		40			67
30000				34	
32000		51	42		

Minimum Threshold Audiogram Curves:

Hearing Thresholds, dB re 20 μPa					
Hz	Amphibia/ Reptiles	Birds	Mammals	Bats	Marine mammals in air
16	65	55	40		
25	58	47	38		
32	51	45.5	37		
40	44	43.8	35		
50	37	42.1	34		
63	30	40.4	32		
80	22	37	27		
100	14	32	18		78
125	10.5	32	17		76.2
200	0	24	12.8		71
250	0.5	11	10		70.5
315	1	12.7	8.1		70
400	1	8	5.8		69
500	2	5.5	3.5		28
630	7	2.8	0.2		28.3
700	12	0.1	-3.6		28.6
800	16.8	-2.6	-7.4		28.9
900	17.1	-9	-11.2		29.2
1000	17.35	-17	-15		29.5
2000	40.2	-17.5	-12.5	92	10
3000	39.9	-12	-12.8	76.6	16
4000	63.3	-18.5	-10	64.3	22
5000	69.3	-15.5	-16.8	45.5	19.4
6000		-18	-16	38.8	16.6
7000		-15	-15.2	32.1	13.8
8000		-10	-11.3	25.4	11
9000		-4	-12.6	18.7	10.4
10000		-6	-14	12	9.9
12000		35	-11.4	10.8	8.8
20000			-4.2	-3	14.8
30000			5.4	2	30.5
32000			5.7	3.3	33
40000			5.9	4.5	
45000			10	5.5	
50000			13	12	
60000			33	-3	
70000			48.7	7	
80000			64.3	23	
81000			63.6	4	
81500			63.2	-4	
85000			60.7	10	
90000			57	21	
95000			62	25	
100000			67.5	29	

APPENDIX VI

Animal Responses to Noise Sources

Note: Animal responses are coded using, firstly, the assessment criteria definitions of Table 5.1, i.e. 0=no effect, S=slight, M=moderate and SV=severe, and secondly, the credibility ratings of Table 5.6, i.e. 1=none, 2=low, 3=medium, 4=high , and 5=maximum.

Animal	Noise Source	Response	Code
CLASS INSECTA (INSECTS)			
Locusts (*Lucustidae*)[474]	Tones of 1, 4 and 10 kHz at 80 dB SPL	Increased movement/flying response	S/4
Indian meal-moths (*Plodia interpuctella*) [475]	Loudspeakers, bells and whistles. General noise (120 – 2000Hz)	75% reduction in emerging Indian meal moth adults following exposure to 120 – 2000 Hz sound during 4 days of the larval stage.	M/3
	General noise (2 – 40 kHz)	Cessation of movement	M/3
Pupal and adult Indian meal moths and flour beetles (*Tribolium* spp.) [476]	Varied frequencies and intensities	Few effects on reproduction were noted, with the exception of mated flour beetles continuously exposed to 40kHz. Even though large numbers of insects were used in many replications, effects of sound exposure were difficult to demonstrate, due to variability in egg production.	O/2
Corn earworm moths (*Heliothis zea*) and flour moths (*Epestia kuehniella*) from 20 to 10 days. [477]	72 hour exposure to pulsed sound (50 kHz), 25 pulses per second at 65 dB SPL	50% reduced longevity. Mean number of eggs per female reduced by 59% in the noise exposed group.	M/4
Midges (*Chironomidae*) [478]	125 Hz at 13 – 18 dB above ambient noise	Increased movement/swarming of males around source	S/4
Honey bees (*Apis mellifera*) [479]	Frequencies between 200 and 2000 Hz, intensities varying from 107 – 119 dB.	Ceased moving for up to 20 minutes and did not appear to habituate to the sound.	M/4
CLASS CRUSTACEA (CRABS, SHRIMPS, LOBSTERS)			
Brown shrimp (*Crangon crangon*) (reared in a soundproof box reproducing acoustics of their natural environment) [480]	Thermo-regulated aquarium where noise levels reached 30 dB in the 25 to 400 Hz range.	Permanently high sound level resulted in a significant reduction in growth and reproductive rates. To a lesser degree, noise also appeared to increase aggression (cannibalism) and mortality, and to decrease food uptake. Symptoms were extremely similar to those induced by adaptation to stress.	SV/4

	SUBPHYLUM VERTEBRATA (VERTEBRATES)		
CLASS SELACHII (SHARKS AND RAYS)			
Sharks [481, 247]	Pure tones and octave bands of random noise	Sharks generally do not detect sounds above 1 kHz and in most cases their best sensitivity is to sounds below 300 Hz. The lemon and horn sharks have best hearing at about 40 Hz.	-
CLASS PISCES (BONY FISHES)			
Herring [482]	Taped sounds from a fishing fleet	Avoidance, alarm, and startle responses	S/3
[483]	Sound pressures of 2–18 Pa [100-119 dB] on wall of tank	Startle responses	S/4
Net-penned Pacific herring (*Clupea harengus pallasi*) [484]	Tape-recorded sounds of a herring fishing fleet, including moving or stationary vessels, sonar, echo sounder	No visible response.	O/2
Salmon (*Salmo salar*) [238]	Sound at different frequencies	Only responded to low frequencies (below 380Hz) Particle motion, as opposed to sound pressure proved to be the relevant stimulus. "Salmon are unlikely to detect sounds originating in the air, unless they are directly overhead, but they are sensitive to substrate-borne sounds". Compared to carp and cod, the hearing of the salmon is poor and more like that of the European Perch (*Perca fluvatilis*) and the plaice (*Pleuronectes platessa*)	S/2
Atlantic salmon [485]	Ambient noise levels 4-16 dB higher than other tanks	5-8% reduction in smolting rates	M/4
Trout and salmon [486]	Sonic booms	No mortality difference between exposed and control groups	O/5
Rainbow Trout (*Salmo Gardineri*) [486]	Sonic boom (max. 4.16 pound/ft^2 (psf) [199 Pa/140 dB])	Slight behavioural reaction	S/5
Yearling Rainbow Trout [486]	Sonic Booms (maximum of 4.16 psf [199 Pa/140 dB])	No or very slight response	S/5
	Simulated sonic booms (maximum of 4.16 psf [199 Pa/140 dB])	Blood glucose levels, blood cortisol levels and plasma osmolarity levels were similar to that of controls.	S/5
Striped bass [197]	Sonic booms from commercial/ small jets	Intense 'focused' booms resulted in fish deaths due to fish jumping out of their tanks or dying of seizures in the water.	SV/4
Pink snapper (*Pagrus auratus*) [487]	145 to 180 dB re: 1 µPa from air gun at 5m depth (gas pressure 10 Mpa giving pulse every 10 secs.	Destruction of sensory hair cells over time	M/4

Asian aya [488]	Underwater sound (200–600 Hz, 72–80 dB)	Jumping response	S/4
Ostariophysi (carps and catfish) [242]		Can detect sounds to over 3000 Hz, best hearing sensitivity at about 500–1000 Hz.	-
Goldfish (*Carassius auratus*) [489]	Pure tone stimulation	300 and 500 Hz produce lower threshold shifts than at 800–1000 Hz. Sensitive frequencies in this species varies from 70 Hz to about 4600 Hz	-
[490]	White noise (0.1 to 4 kHz, 164 to 170 dB Re: 1 μPa)	Significant threshold shifts at all frequencies after 7 days. Further exposure did not produce greater shifts. Thresholds returned to baseline after 14 days.	M/4
Sheepshead minnow/ longnose killi fish [491]	Tanks exposed to high noise levels (up to +30dB above ambient)	Reduced growth rates; reduced viability of minnow eggs	M/4
Marine Catfish (*Arius felis*) [242]		Able to detect sounds from 50–1000Hz, best hearing sensitivity from 100–200 Hz	-
Guppy [492]	Simulated sonic booms (>1 mbar [>100 Pa/134 dB])	Short duration reactions (0.5 s)	S/4
Rockfish [493]	Received Level (RL) re 1μPa rms	No significant response up to 153 dB. Threshold for alarm was 180 dB.	S/4
Flatfish species, two (*Pleuronectes platessa* and *Limanda limanda*) [237]		The species are sensitive to sounds in the frequency range from 30-250 Hz with greatest sensitivity around 110-160Hz. Both species were sensitive to particle motion. The pressure thresholds decreased by several decibels in the presence of an air-filled balloon representing a swim bladder. Comparison between the hearing data for the flatfish and for the cod (*Gadhus morhua*) suggests that differences in performance may be attributed to the necessary role of the swimbladder in the hearing of cod.	-
Fish (anchovy, herring, sardine, surfperch)[494,495]	178 dB re: 1 μPa at 110m from hydraulic pile driver. Each minute of piling operations had 30 hammer strikes	Within 100m of the piling, moribund fish appeared on the surface after only two hammer strikes and fish continued to float to surface during 20 minutes of piling. Damage included ruptured blood vessels and swim bladders.	SV/4
Fish (demersal)[496]	Seismic air gun discharges	Startle response but no effect on schooling behaviour or other routine behaviour	S/5
[497]	Air gun discharges	Startle responses involving faster swimming and formation of tighter schools but habituation with time	S/5
Unspecified (Fish) [498]	Underwater dredging sound (38 dB at 150m or 75 dB at 2m from submerged pipe)	Negative responses, avoidance of the acoustical field of the worksite	S/3

[499]	Shock wave of 0.26 atm [26338 Pa/182 dB] (275 times that associated with a strong sonic boom) due to a bullet travelling at 1,200 m/s a few cms above tank	Fish sensed the passage of the shock wave but suffered no ill effects.	S/3
Fish eggs from cutthroat trout (*Salmo clarkii*), steel head / rainbow trout and Chinook salmon (*Oncorhynchus tshawytscha*) [486]	Sonic booms of military jets (F–111 or F–101) or simulated sonic booms of varying pressure (maximum of 4.16 psf [199 Pa/140 dB])	No effect; no increase in egg mortality	O/5
Fish hatchery [197]	Aircraft noise and sonic booms	No effect on fish at the hatchery.	O/5
CLASS AMPHIBIA **(FROGS, TOADS, SALAMANDERS)**			
Spadefoot Toad (*Scaphiopus couchi*) [364]	Recorded motorcycle sounds (95 dB(A))	Elicited emergence from burrows, a potentially detrimental impact on the population if occurs outside the normal breeding season.	SV/4
Frogs [249]	Single – tone stimuli (1 to 2 sec interval)	The frogs redistributed their calls in time such that the calls fell almost exclusively within the brief time window between tone bursts, thereby avoiding overlap with the tone. The average background noise level at the frogs calling site was 39 dB SPL at 500 Hz, 59 dB SPL at 1000 Hz and 66 dB SPL at 2000 Hz. Avoidance behaviour was observed at stimulus levels barely exceeding the noise floor of the frogs' environment.	S/5
Bullfrog (*Rana catesbieana*) [500]	Measured sound levels the animal itself makes	Choruses about 20dB SPL in the 1.5 to 2.5 kHz frequency band up to 965m above small ponds	S/2
Neotropical treefrog (*Eleutherodactylus coqui*) [249]	Frequencies varied from 230 to 3420 Hz, tones of 605–2000 Hz, presented at 60–70 dB SPL.	Acoustic avoidance behaviour. Below 665 Hz, threshold dropped at 14 dB per octave to a maximum sensitivity of 41 dB SPL at 230 Hz. Tones of 3420 Hz (approx. the 3rd harmonic of the 1st note of the advertisement call) failed to elicit a response even at high levels (over 91 dB SPL in one case)	S/5
CLASS REPTILIA **(TURTLES, SNAKES, LIZARDS, CROCODILES)**			
Green and loggerhead sea turtles [497]	Airgun discharges (166 and 175 dB)	Increased swimming time as noise level increased. 166 dB equated to startle and 175 dB to avoidance levels	M/4
Tuatara (*Sphenodon punctatum*) (a nocturnal crocodilian) [501]		Sensitive to low-intensity sounds due to poor photoreceptors and vision.	-

Desert Tortoise (*Gopherus agassizii*) [168]	Exposures to 20 subsonic overflights over a 40 minute period (levels ranging from 95 to 114 dB SEL). Also a single simulated focus boom of 10.5 psf [503 Pa/148 dB].	No TTS. However, TTS was observed for over 45 minutes after being exposed to 10 simulated sonic booms at 6 psf [287 Pa/143 dB].	M/4
[169]	Sonic booms + F22 subsonic aircraft overflight noise.	8% decrease in heart rate for about an hour after 45 minutes of exposure. Also, 'freezing' response.	M/4
Selected species of lizards from the families of Iguanidae, Gekkonidae, Anguidae and Teidae. [502]	Tone pulses and click stimuli. The temperature of the maximum auditory sensitivity varied as a function of the natural thermal preference of each species. The lowest and highest temperatures at which a response was found varied with lower and upper thermal tolerance levels for the particular species.	All species examined were most sensitive to sounds between 900 – 3,500 Hz. This frequency range was found to contain much potential information of ecological significance to the species (e.g. presence of predators, movement of insects). Average sensitivity loss of 10-20dB/10°C was found in the region of maximum sensitivity.	S/1
Desert iguana (*Dipsosaurus dorsalis*) [257]	ORV noise (114 dB for 1 and 10 hrs)	Loss of hearing sensitivity, shift in hearing threshold. Permanent sensitivity losses.	M/SV /5
Mohave fringe toed sand lizard (*Uma scoparia*) [364]	Taped dune buggy sounds of 95 dB(A), representing the dune buggy at 5m	TTS – Dune-buggy sounds are inherently damaging to the hearing sensitivity of the fringe-toed lizard. Lizards were even vulnerable to noise-induced TTS when buried under shallow layers of sand.	M/SV /5
Indian browntree snake [503]	Airplane passing overhead	Alert behaviour	S/2
CLASS AVES **(BIRDS)**			
	RUNNING BIRDS - RATITES		
Ostrich (*Struthio camelus*), Emu (*Dromaius novaehollandiae*) and Greater Rhea (*Rhea americana*) [194]	Aircraft overflights of more than 2,000 birds in the US. Overflights included UH-1 helicopter at a range greater than 3,000 ft [914m] and a UH-60A helicopter	19 fatalities or a loss rate of 1% of exposed birds. In addition, 7 cases of breeding declines and 2 cases of stress were reported. Further data relating to the responses of more than 3352 birds provided evidence of 3 mortalities at two farms, a leg injury at one, and minor injuries at two others, i.e. a loss rate of 0.2% including injuries. The greatest incidence of risky behaviours was highest when aircraft were directly overhead and at low altitudes.	SV/3
Adelie penguin [504]	Aircraft noise	Caused birds to panic at distances >1,000m, and 3 days exposure to a helicopter inhibited foraging birds from returning to nests, caused population to decrease by 15% and an active nest mortality of 8%	M/3

Emperor penguin chicks[505]	Helicopter overflights (L_{Amax} 68.2 dB)	Chicks became more vigilant and exhibited flipper flapping when helicopters at 1,000m AGL. Disturbance considered to be due to visual as well as acoustic stimuli.	S/4
	DIVERS AND LOONS		
Common loons and arctic loons [506]	Boating and recreational activities/low-altitude aircraft overflights	Sensitive to activities near to breeding sites and readily displaced from nests	M/3
Common loon [507]	Low-level military jets	Undisturbed even when directly under flighpath	O/3
[506]	Boating disturbance	Cases of incubating loons rolling egg out of nest and into water when suddenly disturbed. Eggs not subsequently replaced.	SV/3
Arctic loon [508]	Fixed wing aircraft and helicopters	Birds dived in response to overflights	S/3
[509]	Human presence	Birds left nests for an average of 53 minutes during early incubation after visits to their nests but predation rates were low. Normally, rarely leave their eggs unattended for more than a few minutes at a time but may stay away considerable periods when disturbed.	M/3
	PELICANS		
White pelican [510]	Commercial aircraft (>33ft [>10m])	Stampede, panic, eggs lost, abandoned, eaten	SV/5
Brown pelican [197]	Infrequent low–altitude aircraft: military/ private/ small propeller/ small jet/ helicopter	Low-altitude overflights flushed breeding birds and often caused panic reactions that resulted in lost eggs and young.	SV/5
	HERONS AND STORKS		
Wading Birds, including great egrets (*casmerodius albus*), snowy egrets (*egretta thula*), and Louisiana herons (*hydranassa tricolor*) [203]	Helicopter/fixed wing flyovers, 60–120m	Alert reactions. Any bird that did leave its nest failed to return within 5 minutes; 90% of observations, saw no reaction or the birds merely looked up	S/3
Wading birds [203]	Overflights by a propeller driven fixed wing aircraft and a Bell 47G-2 helicopter	The helicopter caused less short term disturbance than the fixed wing aircraft.	S/3
Cattle egret, double crested cormorant, great blue heron, great egret, white ibis [511]	Military jet (<500ft [<152m])	No effect on colony establishment or size. Nest success, nestling survival, nestling mortality was independent of F-16 overflights, but was related to ecological factors.	O/3
	DUCKS, GEESE AND SWANS		
Wood duck (*Aix sponsa)* embryos [512]	Recorded maternal call of wood duck or mallard 80–82 dB	65% increased bill-clapping during stimulus presentation. 75% receiving mallard call decreased bill – clapping. During each call the heart rates of each embryo increased significantly.	-
Migrating ducks (various species) [513]	Military jet (<3000ft [<914m])	No reaction or minor behaviour changes or flush from lakes	S/3

Ducks (mallards and other dabbling ducks) [507]	Low-level military jet aircraft (>100/day)	Little reaction. Some birds were noticeably startled but did not show strong avoidance responses. Possibility of habituation due to frequent daily exposures.	S/5
Ducks[514]	Aircraft overflights	Ducks showed milder responses than geese and flushing was relatively infrequent (13% of cases)	S/3
[515]	Fighter aircraft overflights (80-109 dB(A), average 85 dB(A))	No strong relationship between disturbance events and number of responses of black ducks (2.6%), American wigeon (6.4%), gadwall (3%) and green-winged teal (7%). Lack of response attributed to habituation.	S/5
Ducks (diving and dabbling) [516]	Helicopter overflights	Non-breeding ducks more sensitive than breeding birds. Females with broods were generally more tolerant than non-breeding or moulting birds.	S/2
Ducks (staging and migrating) [517,518,519]	Boating/human activities	Avoid areas	M/3
Eider ducklings [520,521]	Boat disturbance	Four-fold increase in predatory encounters from gulls	M/2
Trumpeter swan [522]	Fixed-wing and helicopters (200-2000ft [61-610m])	Fixed-wing - stopped activity; head up. Helicopter - flushed from nests.	S/3
[523]	Fixed-wing (740-990ft [226-302m])	Seek cover in tall vegetation	S/3
	Helicopter (500ft [152m])	Cygnets crowd together	S/3
Tundra swan [197]	Helicopter disturbance	Caused flushing and fright behaviour leading to abandonment of nests	SV/3
Geese (Brant and Canada)[524]	Fixed wing aircraft and helicopters: Noise – High >76 dB(A), Low <76; Altitude – 30-760m; Distance – 0 to 2 km.	Brant exhibited flight to 75% of overflights; Canada geese responded considerably fewer times. Lateral distance found to be most important factor in determining geese responses. Helicopters elicited greater responses.	S/5
Black brant geese (*Branta bernicla*) [126]	Flyovers by eagles, helicopters and fixed wing aircraft	Geese oriented the head and took flight in response to aircraft (helicopters and fixed wing) at about double the distances they reacted to eagles. Using a large Bell 205 and smaller Bell 206 and Hughes 500-D, the large Bell produced the largest proportion of responses. Aircraft height was not significant.	S/5
Brant/ tufted puffin/ double crested cormorant/ common murre/ glaucous gull [525]	Military jet (>500ft [>152m])	No response	O/3
	Military jet (<500ft [<152m])	Wing-flapping, flush from perches, abrupt departure of area	M/3
Brant/common eiders (*Somateria mollisima*)/glaucus gulls (*Larus hyperboreus*)/arctic terns (*Sterna paradisea*) [526]	Fixed wing aircraft/humans	Human presence appeared to affect incubating behaviour of birds more than fixed wing aircraft. Non-breeding birds appeared to be more disturbed by people and by both helicopters and fixed wing aircraft than were nesting birds.	S/2
Brant/ emperor geese (*Chen canagica*)/ Canada geese (*Branta canadensis*) [527]	Aircraft and other general noise sources	Eagles, boats and humans on foot caused a greater percent of flight than any category of aircraft; however, the lateral distances to these sources were much less than the aircraft overflights. The Bell 206-B	S/3

		helicopter caused a greater degree of flight response than single engine fixed wind aircraft.	
Brant/ glaucous gull/ arctic tern [528]	Fixed-wing (500-1000ft [152-304m])	Flushing from nests	S/3
	Helicopter (500-1000ft [152-304m])	Disrupt nesting behaviour	S/3
Brant [197]	Military/ private/ small propeller/ small jet/ helicopter	Frequent over-flights, even as high as 3000–4000 ft [914-1219m] above ground cause panic flush and for the birds to leave the area for hours sometimes missing the next low-tide feeding opportunity.	M/3
[529]	Fixed-wing/helicopter (<500-1000ft [<152-304m])	Panic and escape area	M/3
[530]	Fixed-wing/helicopter (<1650ft [<503m])	Fixed-wing - fly away. Helicopter - widespread "panic", lost feeding time.	M/3
[527,531]	Aircraft overflights	Minimum threshold of noise above which geese took flight was 65 dB(A)	S/4
Canada Geese (*Branta canadensis*) (nesting) and brood-rearing Brant (*Branta bernicla*),. two species of loon, four species of geese, Tundra Swans (*Cygnus columbianus*) and ten species of duck [532]	2 gas-turbine compressors at an existing oilfield facility. Low frequencies (31.5 and 63 Hz bands). Long term L_{Aeq} noise levels near the facility increased by almost 3 dB from 52.2 to 54.9 dB.	Canada Geese pre-nesting avoided sites within 500-750m of the facility. Spectacled Eider (*Somateria fischeri*) also displayed a shift in distribution attributed to the avoidance of areas increased by noise. For other species, few changes in abundance and distribution could be attributed to increased noise due to the compressors. In fact, spring weather conditions had a greater effect on both the number and success of nesting birds than did increased noise.	S/4
Canada goose [513]	Military jet (<3000ft [<914m])	Arouse from sleep, alert behaviour, call	S/3
Canada geese and snow geese, opposed to turkey vultures, pronghorns, coyotes and raptors [210]	Low flying helicopter noise	Did not tolerate helicopter noise at any level. Geese were particularly more aggravated than the latter species.	M/3
Snow goose (*Chen caerulescens*) [526]	Cessna 185 (300–1000 ft [91-305m] AGL)	Flight response; reductions of flock size. Geese tended to flush at greater distances when the aircraft was under 1,000 ft [305m] AGL.	M/3
[513]	Military jet (<3000ft [<914m])	No response, minor behaviour changes, flush, circle over, depart or land again	S/3
[533]	Fixed-wing (98-980ft [30-299m])	Leave lake area	M/3
[534]	Gas compressor station noise	Altered flight direction (61% by more than 90 degrees) and also avoided landing	S/3
[200]	Overflights by fixed wing aircraft and helicopters	Birds were flushed sooner in response to helicopters (Bell 206 and Hughes 500) compared to fixed wing aircraft, but the geese actually flew farther in response to small fixed wing aircraft.	S/3
[535]	Fixed-wing (300-1000ft [91-305m])	Flushing of entire flocks and flock sizes were reduced when birds regrouped after severe disturbances	M/3
[508]	Helicopter overflights	Parents driven from nests and took up to 45 minutes to resettle after disturbance had ceased. Gulls and jaegers were observed to prey on unattended eggs.	SV/3

[536]	Simulated noise of a gas compressor station	Feeding flocks seldom approached closer than 800m of sound source	S/3
[537]	Gunfire noise	Showed milder responses as hunting season progressed – possible habituation	S/2
Snow geese and brant [197]	Low level helicopters	Greater response to helicopters than planes. Response commenced when helicopter was more than a mile away and birds did not settle down until several minutes after the helicopter had departed the area.	S/3
Arctic geese (moulting)	Bell 206 and 212 helicopters	Reacted strongly to noise. The larger 212 caused reactions at about 9 km even though the helicopters were not visible.	M/3
White-fronted geese (moulting) [508]	Helicopter overflights at 90m AGL	Flock of 20 with young ceased all activities and adults assumed defensive postures. Incubating geese seldom flushed. However, non-breeding geese at the edge of breeding grounds often flushed at a distance of 3 km or more.	S/3
Waterfowl, particularly geese [514]	Aircraft 150m above ground	Particularly disturbed, especially oldsquaw.	S/3
Oldsquaw, surf scoter [538]	Helicopter (100-750ft [30-229m])	Swim away or dive into water or no response	S/3
[528]	Helicopter (100-750ft [30-229m])	Escape, alert behaviour, dive into water, flock together, change activity budgets	S/3
[536]	Helicopters at 100m AGL	Escape movements (diving or swimming) and general restlessness – overpasses at 300m AGL had no apparent effects. Birds first alerted when helicopter at 230m. Surf scoter generally more sensitive than oldsquaws.	S/3
Oldsquaw(*Clangula hymalis*) [514]	Low-level aircraft overflights (150m AGL)	Stronger response than higher overflights	S/2
Waterfowl/seabirds [539]	Sonic booms 72 – 89 dBA	Startle responses; flushed off nest	S/5
[540]	Simulated sonic booms 115.6-145.5 dBA	Birds within 100m of cannon flushed and circled; returned to roost within 2–10 minutes	S/5
[526]	Float plane disturbance over 3 days	Decreased waterfowl population on small lake. Population of a control lake remained stable until a bald eagle caused 45-50 birds to leave.	M/3
[197]	Agricultural spraying by aircraft	Flushing of waterfowl, especially geese, and driving birds off Refuge. Aircraft-induced stress believed to be making waterfowl more susceptible to disease, especially during winter.	M/3
[197]	Military helicopters	Virtually all Refuge ducks, geese, and swans take flight at the sound of approaching helicopters and remain airborne until the aircraft can no longer be heard.	S/3
[197]	Commercial/ private/ small propeller/ helicopter	Birds more likely to leave an area when disturbed by helicopters; they appear to be more sensitive to the 'chopping sound' from a much greater distance than the sound of a fixed-wing aircraft.	M/5

Waterfowl (moulting) [526]	Helicopters	Driven from land by helicopter disturbance 100 yds [91m] from shore at altitudes of 100-750 ft [30-229m] AGL.	S/3
	BIRDS OF PREY		
California Condor (*Gymnogyps californicus*) [541]	Blasting, drilling, sonic boom, low altitude aircraft	Adults flush from nest; some nests abandoned	M/3
Bald Eagle (*Haliaeetus leucocephalus*) [542]	Aircraft overflights	Helicopters and small jets had the greatest effect. Reacted to civilian passenger jets 11% of the time, propeller aircraft 2%, helicopters 40% and small jets 55% of the time.	S/3
[197]	Private/ small propeller	No adverse effects on breeding (4 year study)	O/3
[163]	Over 700 various events associated with human activity having the potential to cause disturbance.	The highest frequencies of response were associated with the presence of anglers, cars and gunshots. The birds showed a far greater response to gunshot (76%) than artillery noise (0%).	S/3
[543]	Light fixed wing aircraft at 15-60m	Brooding eagles not flushed from nests	O/3
[98]	Aircraft at 20-200m	Only 9% of perched birds flushed during nesting season	S/3
[164]	Fixed-wing aircraft at average distance of 600m	30-50% appeared alerted by aircraft, but only a few birds flushed. Birds most sensitive when foraging. Human activities at 72m likely to elicit a high response >70%. Recommended aircraft excluded within 625m of foraging habitats and 1,100m from nest sites.	S/3
[544]	Fixed-wing aircraft	U.S. Fish and Wildlife Service (USFWS) recommend that fixed-wing aircraft should avoid flying less than 150m above ground level (AGL) over eagle habitats during the breeding season	-
[219]	Artillery noise	Eight active nests in 1990 increased to 14 in 1995 and 24 in 1996. During a 2 second period after noise events, 92.7% of the time no change in eagle activity was observed, and 0.7% of the events caused head-turning.	O/3
[165]	Weapons-testing impulsive noise (80-129 dBPeak)	Response one of 'no activity' for approximately 93% of the time. 'no activity' response reduced to 73% at roosting sites, but the greatest activity was only 'head turning' and there was no significant difference in nesting success between exposed and control sites.	S/5
Bald eagles, golden eagles (*Aquila chrysaetes*), peregrine falcons (*Falco peregrinus*), gyrfalcons (*Falco rusticolus*) and rough-legged hawks (*Buteo lagopus*) [545]	Jet engine and piston engine helicopters	Jet engine helicopters (high frequency) seemed less disturbng than piston engines (lower frequency). Birds were least disturbed when helicopters flew parallel to cliff at distance of 0.5 mile [0.8 km]. Sudden presence of helicopter over cliff top caused panic and frantic escape behaviour. Visible approach caused less disturbance. Disturbance just before egg laying, during egg laying, and during incubation was more deleterious than during nestling stage (though appearance of helicopters during late nestling, i.e. when birds ready to fledge, may cause premature fledging). Avoid overflights during	M/3

		inclement weather to avoid chilled eggs or young if adults are flushed off nest.	
Golden eagle [543]	Light fixed wing aircraft at 15-60m AGL	Did not leave nests after repeated close overflights over 116 nests	O/3
Peregrine falcon, Coopers hawk, common black hawk, Harris' hawk, zone-tailed hawk, red-tailed hawk, golden eagle, prairie falcon [546]	Military jet (<980ft [<299m])	"minimal response" or alarm behaviour or fly from perch or nest, no effect on raising young	S/3
Peregrine falcon [547]	Helicopter (<2000ft [<610m])	Responses varied from none to severe	SV/3
[548]	Aircraft	Response influenced by distance and stage of nesting cycle; reactions greater during nestling than incubation.	S/2
Nesting peregrine falcons [547]	Helicopters at mean distance of 718m and fixed wing aircraft at mean distance of 533m	No reactions or only mild response (looking toward). Helicopters elicited moderate reactions (cowering, flight intention movements) in 13% of observations, 6.8% for fixed wing.	S/3
Nesting peregrine falcons and other raptors [167]	Low level jet noise and sonic booms (noise levels ranged from 82-114 dB(A))	Birds were noticeably alarmed and occasionally flushed from nests, however, no significant change in heart rate was detected nor was there any reproductive failure.	S/4
Peregrine falcon nests [173]	258 jet overflights at altitudes below 400m, 111 overflights registered noise levels of at least 85 dB(A)	No females responded by taking flight and only eight males reacted in this way	S/4
Prairie falcon [549]	Industrial blasting	Flushed from eyries 22% of the time, but all birds returned to nests within 3.4 minutes on average. Perched birds more likely to flush than incubating and brooding.	S/3
Gyrfalcon [550]	Helicopter, fixed-wing (500-1000ft [152-305m])	Fly away, alert behaviour, no nest abandonment, no effect on daily activity patterns, may avoid returning to breed in following years	S/3
Gyrfalcons and other arctic raptors [212, 213]	Helicopters at 150-300m AGL	More overt responses were elicited by helicopters at 300m AGL than at 150m AGL.	S/3
Gyrfalcons [212, 551]	Aircraft	Gyrfalcons more sensitive to aircraft disturbance than other raptors. Distance and season affect response. Little reaction to helicopters at >100m during foraging. Sensitivity increased during nesting season. Frequently flushed from nests at 150m and 'stress' posture assumed at 300m AGL.	S/3
[552]	Aircraft overflights	13 of 27 active nests deserted during early nesting period	SV/3
Eagles, hawks, falcons [167]	Low altitude jets and sonic booms 82 – 114 dBA	Noticeably alarmed responses	S/4
Ferruginous hawk [553]	Fixed-wing (<100ft [<30m])	No response	O/3
Red-tailed hawk [211]	Helicopter (100-150ft [30-46m])	Flush from nests, no effect on raising young. Previous limited exposure – 50% flushed from nests. Frequent helicopter exposure – 8% flushed from nest.	S/3

	Army UH-1 Huey (equivalent to Bell 205) at 40-110m	40% of birds flushed at overflights at about 40-110m.	S/3
[197]	Commercial airport noise	Birds appear to readily adjust to airport noise.	S/3
Kites [554]	Low jet overflights (78-89 dB(A))	Behavioural response limited to 'watching aircraft fly by'	S/4
Northern harrier [555]	Jet aircraft at 1,500 ft [457m] to side + explosion of practice bombs (80-87 dB)	Harrier continued hunting at a height of 15-20 ft [5-6m] throughout bombing runs. Activities seemed to be focused on target area – stalking flushed animals?	O/4
Osprey (nesting) [179]	Low-level passes of CF18 jet aircraft over active nests at distances ranging from an exclusion distance of 2.5nm down to directly overhead at speeds of 400-440 knots [460-506 mph/204-224 m/s]. The maximum noise levels varied from 52-101 dB, with rapid onset rates of 26 dB/second.	No significant difference in nesting behaviour was observed to result from the different overflight distances, noise levels or nesting periods during 139 overflights.	O/4
[180]	Low-level jet overflights	No overt reactions apart from adults showing alertness and occasional adjustments in incubation posture.	S/3
[556]	Helicopter surveys	Incubating birds did not flush	O/3
[197]	Private/ small propeller aircraft	Birds in frequently overflown areas believed to habituate to low-altitude aircraft, but nesting osprey in seldom overflown areas do not appear to habituate and exhibit flight/fright behavior.	S/3
[557]	Logging activities/lorries	Pair of ospreys appeared undisturbed	O/3
[558]	Motorboats	Panic escape with damage to some eggs	M/3
	FOWLS, TURKEYS, PHEASANT ETC.		
Domestic Chicken [539]	Simulated sonic booms 156.3 dB	Decrease in weight of 19 day old chicks	S/4
[127]	General noise 100 dB	Increase in 11–hydrocorticosteroid in blood plasma	S/1
[559]	Aircraft noise (3 or more days)	Reduced egg production by keeping hens from feed and water due to noise stress	M/3
[560]	Aircraft flyover noise at 80 to 115 dB at 300 to 600 Hz	No difference in weight gain, feeding efficiency, meat tenderness or yield, or mortality between exposed and control chicks.	O/5
[190]	Aircraft flyovers (96 dB in incubators)	No measurable effect on hatchability or quality of chicks. Sound intensities of 115 dB were effective in interrupting brooding.	O/5
Chickens [183]	Overflights by F4 f Phantoms,	5-7 day old chicks inside light shelters climbed on top of each other though phenomenon diminished over three days of overflying. 3-5 week old chickens showed only orientation behaviour and undirected locomotions, whereas laying hens showed orientation behaviour on the first two days only, with diminishing reactions and even sleeping on	S/3

		the third day.	
[183]	Overflights by a hovering BO105 helicopter	Elicited greater responses than for fixed wing overflights.	S/3
Prairie chicken [197]	Military/ small jet/ large jet/ helicopter	Low-altitude aircraft had no adverse effects.	O/5
[197]	Commercial airport noise	Birds appear to readily adjust to airport noise.	O/5
Turkeys [188]	Aircraft overflights	Habituated very rapidly, and turkeys exposed to chronic worst-case aircraft overflight noise were found to grow at the same rate as control animals although they had some behavioural differences and were found to be more difficult to handle.	S/3
[189]	Low-level jet aircraft noise, 110-135 dB	No decrease in egg laying	O/4
Wild Turkey (*Meleagris gallapavo*) [561]	Real and simulated sonic booms 300–500 ft [91-152m] from nest (0.4 to 1.0 psi [2.76-6.90 Pa/103-111 dB])	Displayed a few seconds of head alert response but were not flushed off their nests and there was no change to brood productivity. In a study of 20 brood groups exposed to sonic booms no hen abandoned her poults, nor did they scatter.	S/4
Pheasant (*Phasianus colchicus*) [562]	Simulated sonic booms at 0.75 km	Laying habits not adversely affected	S/3
Bobwhite quail (*Colinus virginianus*) [166]	Real and simulated sonic booms (100-250 mN/m^2 [0.1-0.25 Pa/74-82 dB])	No change to hatching success	O/4
Japanese Quail [563]	General Noise 100 – 8000 Hz, 80 dB during last 3 days of incubation	Accelerated hatching	S/4
Chukar (game bird) [513]	Military jet (<3000ft [<914m])	Flush or no response	S/3
	CRANES AND RAILS		
Waterfowl, whooping cranes and sandhill cranes [197]	Commercial/private/ small propeller/helicopter	Whooping cranes believed to have habituated to low-altitude light aircraft overflights but flushed at the approach of low-altitude helicopters and remained away from the Refuge until the noise level returned to ambient. Sandhill cranes flushed at the approach of light aircraft and have apparently not habituated. A response threshold has been determined to be 500 ft (152m) minimum above ground level.	S/3
Nesting sandhill cranes [143]	Highway traffic at 4m from the nest and large trucks at 200-300m from the nest	Birds remained undisturbed	O/3
	Helicopter flyovers as low as 40m	82% of the time birds remained on their eggs.	S/3
	WADERS AND GULLS		
Lapwings (*Vanellus vanellus*) [562]	Simulated sonic booms, (50-860 mN/m^2 [0.05-0.86 Pa/68-93 dB]) 95–220m from nest.	Birds unperturbed by boom, laying, incubation, hatching and chick rearing continued in a “natural manner”.	O/4

Herring Gull (*Larus argentatus*) [564]	Colony noise + distant traffic – 77 dB(A); jet aircraft 91.8 dB(A) (non-SST), 108.2 dB(A) (SST)	Subsonic jets had no effect on nesting gulls. Supersonic jets caused significantly more gulls to fly from nests and engage in fights when landed. Eggs were broken during fights and subsequently eaten by predators.	M/3
Populations of gulls (*Larus* spp.), pigeons (*Columba* spp.), raptors and crows (*Corvus* spp.). [565]	Aircraft	Observations were made at several airports in France, and data were also collected from systematic hunts to reduce avian populations; a potential source of aircraft collisions. Gulls appeared to increase at airports, however, the increase appeared to be related to bioclimatic conditions than acoustics.	S/1
Crested Tern [181]	Acoustic stimuli simulating overflights by a fixed-wing DHC-2 beaver float plane	Greatest responses of preparing for flight only occurred when noise were greater than 85 dB(A).	S/4
[182]	Commercial aircraft (250-1000ft [76-305m])	Scan sky, alert behaviour, startle and escape	S/3
Sooty tern (*Sterna Fuscata*) and brown noddies (*Anous stolidus*) [122]	Daily sonic booms from jet planes, some strong enough to smash windows.	50,000 pairs of sooty tern and 25,000 pairs of brown noddies laid eggs ready for season and incubated normally. Brown noddy chicks all hatched successfully but only 245 sooty tern chicks were present when the expected number was 20–25,000. 98% reduction in reproduction of the colony. Un-hatched eggs were still in incubation; some had dead/ unformed/ deformed birds inside.	SV/3
Brunnich's guillemot, kittiwake [208]	Helicopter, 0.5-3 miles [0.8-4.8 km] distance	Birds sometimes responded to a helicopter at a distance of 6 km and always by a distance of 2.5 km, no egg or chick loss	O/3
Incubating colonies of herring gulls, kittiwakes, guillemots, fulmars, shags, razorbills and puffins.[566]	Aircraft overflights (100m)	No effect on the attendance of incubating and brooding birds	O/3
	PIGEONS AND DOVES		
Mourning doves (*Zenaida macroura*) [166]	Sonic booms from overfl;ying aircraft - 2-3 times/week	No evidence that sonic boom disturbance affected phases of bird reproduction.	O/3
	PARROTS AND PARAKEETS		
Budgerigars [567]	169dB (peak SPL) impulse noise	PTS was emphasized at low frequencies and nearly absent at higher (4kHz). About half the duration of noise is required to cause PTS in birds compared to mammals.	M/4
	OWLS		
Mexican Spotted Owl (*Striz occidentalis lucida*) [568]	Helicopters (HH-60G) and chain saws	Chain saws at comparable distances were more disturbing than helicopter overflights, and short duration, single pass overflights had little impact beyond a protection zone of 100m. During the nesting season, owls did not flush when the SEL was <92 dB(A), and the same circumstances applied during the non-nesting season.	S/4

[218]	Chain saws	During the nesting season, the owls did not flush when the $L_{Aeq\ 10\ sec}$ from the chain saw operation was <46 dB(A). For the non-nesting period, the level below which flushing did not occur was 51 dB $L_{Aeq\ 10\ sec}$. A separation distance of approximately 100m was proposed in order to prevent any negative impacts such as flushing.	S/4
[569]	Tornado and F-16 aircraft (40-142 overflights during each 4 month period)	Topographic variables, rainfall and habitat type are important predictors of owl occupancy. Owls did not exhibit escape flights from roosts or nests after exposure to jet overflights. Closest approach was 100m. (A-weighting rather than C-weighting was used a conservative estimator of bird hearing.)	S/4
Burrowing owl [570]	Road traffic noise	Sometimes became alert or moved when nearby road traffic increased but nesting productivity was unaffected	S/3
	WOODPECKERS		
Red-cockaded woodpecker[220]	Military training exercises	Few overt responses to noise; no significant difference in breeding success between disturbed and undisturbed sites	O/3
[221]	Weapon noise - .50 caliber machine gun and artillery simulators	No significant effect on reproductive success	O/3
	PERCHING BIRDS – PASSERINES		
Songbirds [114]	F-111 flyovers at 20,000-41,000 ft [6096-12496m] at Mach 1-1.55 [~670-1040 mph or 297-461 m/s]; peak overpressures were 0.55-3.25 psf [26-156 Pa/122-138 dB]	Songs were completely silenced 4-8 seconds before arrival of audible sonic boom – coincided with arrival of seismic signal through ground	S/5
Songbirds (migrating – nocturnally) [571]	Ground recordings of bird vocalisations and thunder	Flightpaths of migrating birds observed by radar. Bird vocalizations sometimes caused birds to change height. Thunder elicited turns away from noise, especially in cloudy weather.	S/3
Song sparrow [150]	Range of locations where ambient noise levels were between 50-75 dB (linear)	Increased singing rate with increased ambient noise level. Effect only observed in song sparrow.	S/4
Chiffchaffs (*Phylloscopus collybita*) [572]	Songs from their own species and others.	No preference shown between songs. When sound pressure of songs reached 75 dB heart rates were altered. Songs of 50 dB had no effect.	S/4
Lapland longspur (*Calcarius lapponicus*) [526]	Low altitude helicopters	Lower hatching and fledging success; higher nest abandonment; premature disappearance of nestlings – but no overall effect on population density	M/3
[528]	Fixed wing/helicopter (50ft [15m])	No avoidance of nest sites, nestlings died	M/3

Mockingbirds (*Mimus polyglottos*), cardinals (*Cardinalis cardinalis*) and lark sparrows (*Chondestis grammacus*) [166]	Sonic booms from overfl;ying aircraft - 2-3 times/week	No evidence that sonic boom disturbance affected phases of bird reproduction.	O/3
Unspecified (songbird) [114]	Sonic boom 1.15 mean psf [55.1 Pa/129 dB]	Continuous songs of birds were completely silenced 4 – 8 seconds prior to the arrival of the audible sonic boom; raucous discordant cries for a few seconds when boom was audible, returned to normal songs within 10 seconds after the audible boom.	S/5
Canary [573]	White noise 95 – 100 dB continuously for 40-200 days	Hearing loss 20-60 dB	M/4
[150]	Helicopter noise	Pair formation and success of fledgling chicks was not affected by weekly L_{Aeq} of 81 dB at the Marine Corps Air Station, Miramar.	O/4
Woodland breeding birds [147]	Traffic noise > 50 dB $L_{Aeq\ 24\text{-hour}}$.	Decrease in breeding density. Effects extend to a distance of approximately 500m in willow plantations and open poplar woods, and approximately 250m in dense woodland.	S/4
Meadow birds (godwit, lapwing, oystercatcher, redshank, snipe, curlwe, shoveler, garganey, wagtail, meadow pipit and skylark) [574]	Railway noise $L_{Aeq\ (24\ hour)}$	Reduced densities of meadow birds close to railways compared to undisturbed areas. Noise immission had a significant negative effect on density of garganey, godwit, skylark, all meadow birds together, and all waders together. The threshold noise levels above which densities were affected were godwit 45 dB(A), skylark 42 dB(A) and gargeny 49 dB(A).	S/4
Ravens (*Corvus corax*) [358]	Sonic boom jet aircraft	2 or 3 ravens perched on hill, as aircraft flew over, ravens agitatedly called out and small groups collected within 5 minutes, 60 – 70 ravens were present, soaring, flapping and chasing each other, noisily, with in 10 minutes the birds started to disperse and the calling died down considerably. However about 30 ravens were still soaring over the hill an hour after the boom.	S/3
	MISCELLANEOUS		
Migrating birds [297]	Tone sounds- 400 ms 2 kHz	Only 3 of 96 birds deviated from a straight and level flightpath and showed only a slight change to height or rate of climb	S/2
[575]	Human presence	Migrating flocks flushed at greater distances than more solitary resident birds. (Migrating birds may be less familiar with their surroundings and hence take longer to find secure areas following a disturbance.)	S/3
CLASS MAMMALIA (MAMMALS)			
Mammals [576]	Above 90dB	Retreat from source, freezing or a strong startle response	S/4
	Below 90dB	Behavioural responses vary, dependant on noise type or level	S/4

Rhesus Monkey [577]	General noise ($_{Laeq\,(24hr)}$ 85 dB)	Increased blood pressure	S/4
Monkeys [64]	Ttraffic noise of L_{A10} >84 dB for 12 hours/day	Showed an initial increase in heart rate followed by a decrease after a few weeks of exposure. Possible that the decrease was due to a slow rise in blood pressure reflexively affecting the heart rate. Some individuals showed an anticipatory heart rate reaction in the morning before the start of exposure, which is an example of conditioning.	S/4
Domestic Rabbit [578]	White noise 107 – 112 dB	Increased adrenal weights; decreased spleen and thymus weights	S/4
[579]	White noise 102 – 114 dB	Change in the hypothalamus; higher plasma cholesterol and plasma triglycerides; fat deposits in the irises of the eyes; more aortic atherosclerosis and higher cholesterol content in the aortas	S/4
[580]	Electric bell 95 – 100 dB	Enlarged ovaries; persistent estrus; follicular hematomas	S/4
Cottontail rabbit (*Sylvilagus floridanus*) [581]	Snowmobile noise (35-95 dB(A))	Neither the noise nor the presence of snowmobiles caused rabbits to leave the areas that they normally inhabited. However, the presence of snowmobiles increased animal movements (and hence their energy expenditure) within and near their home ranges.	S/4
Arctic hare [582]	Helicopters flying at 70 kph at a height of 30m	Resting hares flushed from cover, potentially exposing them to predators	M/3
Chinchilla [583]	Simulated sonic booms; general noise 65 – 105 dB	Hearing loss, outer cell damage of the cochlea	M/4
Guinea pig [584]	General noise (128 dB, 500 Hz for 20 minutes)	Hearing damage/hearing loss	M/4
[585]	Simulated sonic booms (130 dB at 1/sec)	Damage to approximately 10% of hair cells in first turn of cochlea	M/4
[586]	Sonic booms (20-50 mbar [2000-5000 Pa/160-168 dB], 300 msec)	Slight perception loss and slight lesions of eardrum after exposure to frequent booms	M/4
[587]	SST Concorde sonic boom	Slight and temporary auditory loss noticeable for a 40 mbar [4000 Pa/166 dB] pressure wave (40 times more intense than the sonic boom)	S/4
Red squirrel [205]	Helicopters, bulldozers and people	Reacted more to helicopters, bulldozers that came close, and people on foot than to bulldozers at a distance, blasting, and non-tracked vehicles. Reacted only to noise of helicopter when helicopter also visible	S/3
Desert kangaroo rat [364]	ORV noise 78–110 dB	Temporary threshold shift in hearing. Hearing impairment lasted for up to 3 weeks	SV/5
House mouse (*Mus musculus*) [588]	Rural field levels (80-85 dB) and airport field levels (80-120 dB)	The airport mouse had larger adrenal glands than the rural mouse, to determine if noise was the cause, rural mice were subjected to 105 dB recorded jet noise and increase in the size of adrenal gland was observed, in comparison to controls.	S/5

Mouse [583]	Simulated sonic booms	Auditory damage; inner ear bleeding	M/3
[29]	15-50 Hz at 115-118 dB	Increased muscular fatigue	S/4
[589]	Intermittent noise 110 dB	Decrease in circulating eosinophils; adrenal activation	S/4
[590]	Recorded subway noise 105 dB SPL 4 times daily.	Longer time interval between litters; lower weight gain of young; increased incidence of miscarriage, resorption and malformations	M/5
[591]	Continuous, high intensity jet engine noise (127 dB); random onset noise 103–110 dB; high frequency noise (113 dB)	Decreased pregnancy rate; decrease in number of implantation sites per litter and fetolethal effects (high intensity jet noise)	M/4
[592]	General noise 106 dB	Teratogenic effects	M/4
Rat [127]	General noise 105 dB	Hearing loss; damage to inner ear structure	M/4
[593]	General noise 80 dB	Vasoconstriction	S/4
[594]	General intermittent sound	Rise in blood pressure; hypertension	S/3
[595]	Recorded thunder claps 98–100 dB, 50–200Hz	Increased urinary excretion of sodium and potassium; excretion of oxytocin and vasopressin	S/4
[596]	Electric buzzer 110 dB	Decreased adrenal, body, thymus, spleen, liver, pituitary, ovary and uterine weights; slight gain in thyroid weight increased production of ACTH; inhibition of gonadotrophin, ovarian hormones and possible inhibition of the thyrothrophic and thyroid hormones	S/4
[597]	General noise 1 kHz , 95 dB	Suppressed thyroid activity	S/4
[598]	General noise 120 Hz , 95-105 dB	Reduced gluthathione levels in blood, increased adrenal weights and ascorbic acid; decrease in total adrenal cholesterol	S/4
[30]	Intermittent noise 95 dB	Increased secretion of catecholamines in the urine; increased free fatty acids in the blood plasma; increased weight of the adrenals; inhibition of growth	S/4
[599]	General noise 92 dB	Persistent vaginal estrus prolonged vaginal cornification; higher preweaning mortality of young	M/4
[579]	White noise 102 – 114 dB	Change in the hypothalamus	S/4
[580]	Electric bell 95 – 100 dB	Enlarged ovaries; persistent estrus; follicular hematomas	S/4
[600]	General noise	Decreased fertility	M/3
Cotton rat [601]	Recorded aircraft noise 110 dB	Increased body weights; increased secretion of ACTH	S/4
[602]	High pitched whistles	Enlarged ovaries; persistent estrus; follicular hematomas	S/3
Various species (lab rodents and rabbits) [603]	General noise 150 Hz – 40 kHz, 132–140 dB	Anxiety-like behaviour	S/4
Marine mammals [408]	Received level (RL) of 140 dB re 1μPa rms	Most actively avoid the area of the noise source.	S/4

[408]	RLs up to 155 dB re 1μPa rms	Low Frequency Sound Scientific Research Program (LFS SRP) showed no response or only temporary behavioural response with no lasting biological significance, such as brief cessation of vocalisation by some humpback whales and resumption of normal behaviour within ten or so minutes.	S/4
[408,604]	Single Ping Equivalent (SPE)	At levels below 120 dB the risk of non-injurious harassment was zero; for an SPE of 150 dB the risk was 2.5%; at 180 dB the risk was 95%; and above 180 dB the risk approached 100%.	-
[409]	Test transmitted signals of 209-220 dB re 1μPa tones centred on 57 Hz at a depth of 175 m	Forty schools of cetaceans and 19 pinnipeds were sighted before the transmission and 40 schools and 25 pinnipeds were sighted after. Schools of hourglass dolphins (*Lagenorhynchus cruciger*) increased and schools of mid-sized whales, mainly southern bottlenose whales (*Hyperoodon planifrons*) and minke whales (*B. acutorostrata*), decreased, with no obvious cause for these changes being observed and no consistent changes in direction of travel.	S/4
Bottlenose dolphin (*Tursiops truncatus*) and white whale (*Delphinapterus leucas*) [605]	Intense 1-second duration tones at 400 Hz and 3, 10, 20 and 75 kHz.	Stimuli between 192 and 201 dB re 1μPa were required to induce 6 dB or larger TTSs, except at 75 kHz where 182 dB caused TTS in one dolphin and another showed no TTS up to 193 dB, and at 0.4 kHz where no animals showed TTS at levels up to 193 dB.	S/5
[606]	Single impulse exposures of peak pressure up to 226 dB re 1μPa for the whale and 228 dB for the dolphin	TTSs of 7 and 6 dB were found in the whale at 0.4 and 30 kHz respectively but thresholds returned to within ±2 dB of pre-exposure value within 4 minutes. No TTS was found in the dolphin	S/5
Bowhead Whale (*Balaena mysticetus*) [514]	Boat traffic	More wary and easily displaced during spring as opposed to autumn.	S/3
Southern right whale (*Eubalaena australis*) [607]	Sounds made by the whale are not random, but are intimately related to the social context and activity of the animals. A resting whale does not call very often but sometimes makes long moans while exhaling through its nostrils. A swimming whale that is alone and seeking other whales makes "up-calls". Excited whales make high calls, hybrid calls, pulsive calls, flipper slaps and loud forceful blow sounds. Not yet determined is whether some variable in the contact call encodes for the identity of the caller and whether the more complex associations among variables in the sounds from active whale encode for some subtle parameters of the social context.		-
Beluga whale (*Delphinapterus leucas*) [514]	Boat traffic	Easily displaced esp. when feeding	S/3
	ORDER CARNIVORA (FLESH EATING ANIMALS)		
Domestic dog [608]	Sudden loud noises	Increase in plasma corticosteroid concentrations	S/3
Adult watchdogs [183]	Aircraft and helicopter overflights	Strongest reaction to fixed-wing aircraft.	S/2
Wolf [609]	Low altitude fixed wing aircraft and helicopters	Startle reaction; running	S/3

[610]	Low-level aircraft	Most wolves ran at approaches <61m, but only 30-50% reacted when distance 61-305m	S/3
Fox [611]	Aircraft overflights	Little reaction at distances >300m. Mild responses to humans on foot at 150m or more.	S/3
Grizzly bear [612]	Helicopter (>3280ft [>1000m])	"Mild" behaviour response or run away	S/3
	Low altitude fixed wing aircraft and helicopters	Startle reaction; running	S/3
[201]	Fixed-wing (>1000ft [>305m]),	Interrupt activity/leave area	M/3
[96]	Fixed-wing (200-500ft [61-152m]), helicopter (200-500ft [61-152m])	Run towards cover	S/4
[613]	Aircraft overflights	Strong avoidance behaviour	M/3
[614,615]	Underground blasts at 1-2 km	Bears in dens monitored by telemetry – brief periods of movement but did not leave dens or otherwise disrupt their winter hibernation	S/3
Farm-raised mink (*Mustela vison*) [162]	3 sonic booms (average 294 N/m^2 [294 Pa/143 dB])/3 simulated sonic booms (average 167 N/m^2) [167 Pa/138 dB]) - structural vibrations of 10 m/s^2 or less	Brief startle reaction, no long term effect on health and well-being of females and new born kits. Most mink returned to pre-boom activity within 2 minutes.	S/4
[157]	Sonic booms	Female mink with kits may be alerted, pause in activity and look for the source of the noise; sleeping females may awaken; mating pairs may show momentary alertness but otherwise no disturbance; - no wounding, killing, carrying, or burying of kits in nests was observed in response to sonic booms. Reactions of mink to barking dogs, truck noises and mine blasting similar to the reactions to sonic booms.	S/3
[183]	Jet aircraft and helicopter overflights	Straight ahead overflights by both fixed-wing aircraft and also helicopters caused lesser responses than hovering helicopters that produced quite short but stronger responses.	S/3
[204, 183]	Aircraft noise	Little response to fixed and rotary-winged (BO 105) noise in the absence of visual cues. When the noise event was coupled with a visual stimulus, i.e. the aircraft could be seen by the mink, the animals oriented towards the stimulus.	S/3
Domestic cat [616]	Noisy laboratory	Hearing threshold shifts; loss or damage to hair cells of inner ear	M/3
[617]	General noise 100–1000 Hz	Hearing threshold shifts	S/3
Pinnepeds (seals, sea-lions, walruses) [539]	Sonic booms 80–89 dB(A)	Elicited more startle reactions than 'soft' booms at 72-79 dB(A)	S/4
Harbour seal, sea lion and elephant seal [618]	Varying levels of octave band noise	Lower levels for onset of TTS of 137, 150 and 148 dB re 1 μPa respectively.	S/4
Seal [619]	Aircraft	Seals from areas subjected to loud naturally occurring noises, e.g. crashing icebergs, were more tolerant of aircraft disturbance and	S/3

		habituated sooner than seals from quieter environments	
620	Light fixed wing aircraft at 100-150m AGL	Caused 25-40% of hauled-out ringed seals to dive	S/3
621	Seismic activity	no difference to population densities between exposed and control areas;	S/3
622	Seismic activity	seals 2-4 times more abundant in control area.	M/3
Harbour seal [525]	Military jet (<500ft [<152m])	Leave rocks, enter ocean	S/3
623	Startle noises – 1-100 kHz sounds;recorded killer whale calls; loud noises (banging and shouting); metallic scraping.	Seals quickly habituated to the noises after several trials	S/3
Elephant seal and sea lion [540]	Impulse noise created by a carbide pest control cannon (116 dB(A)/126 dBLin at 50m, 146 dB(A)/147 dBLin at 5m)	Alert behaviour in 74% of males, 65% of females and 26% of pups. Animals returned to normal activity within a few minutes and there was no habituation. Alert reaction to human intrusion lasted longer. During the non-breeding season over 70% went down to water after simulated sonic boom.	S/4
Northern Sea lion [525]	Military jet (<500m)	Leave rocks, enter ocean	S/3
Atlantic walrus [140]	Helicopter (4270ft [1301m])	Raise head towards aircraft or shift body position or leave rocks and enter ocean	S/3
Horses [183]	Low level overflights by fixed wing aircraft (Fiat G91, F104 g (Starfighter), F4 f (Phantom), ALPHA jet and A10 (Warthog)) and three helicopters (Alouette II, BO105 and Bell UH1D).	Group of horses in a large paddock showed very intensive flight reactions along the fences or random movements within the paddock, especially when the aircraft could be seen approaching. The fences were never broken or passed, but occasional biting or biting-threats as well as kicking or kicking-threats were observed. The visible excitement did not last for longer than 2 minutes.	S/3
Mares (pregnant) [184]	Aircraft noise	All exposed mares delivered live normal foals without assistance. However, exposed mares did show significant differences in the level of anxiety and movement compared to control animals, and their heart rates increased during noise events, but no injuries occurred and no ectopic arrythymias were observed. Overall, some behavioural and physiological adaptation to the noise events was observed.	S/3
Pigs [127]	120 dB for 6 hours	Increase of plasma 11–OH–corticosterone and catecholamines	S/4
127	Engine noise, 108 dB for 72 hours	Decreased corticosteroid level, immediately followed by an increase after stimulation ceased. Biphasic response gave negative feedback effect on anterior pituitary, responsible for releasing ACTH which activates adrenals during stress. Sound exposure at least short term, influences several hormone systems in pigs	S/4

[185]	Recorded aircraft noise (propeller/jet) 100-120 dB	No impact on conception rate or weaning. No significant differences in feeding or weight gain from pigs unexposed to the noise	O/4
Pigs (pregnant sows in stables and open pasture) [183]	Low level overflights by fixed wing aircraft (Fiat G91, F104 g (Starfighter), F4 f (Phantom), ALPHA jet and A10 (Warthog)) and three helicopters (Alouette II, BO105 and Bell UH1D).	Some intensified wagging of tails, but even when 'chased' by helicopters at a height of only 5m the pigs exhibited only slow trotting action for brief periods.	S/3
Castrated Male Pigs [624]	93 dB (unspecified frequency)	Excess secretion of hormones, water retention and sodium retention. Also , excess aldosterone may be induced by stress, resulting in the upset the electrolyte balance, which can be manifested by hypertension (possibly due to sodium and water retention), excessive urination and thirst.	S/4
Swine[624]	General noise 93dB	Aldosteronism (excess secretion of aldosterone from the adrenals)	S/4
Mule deer (*Odoncoileus hemionus crooki*) [513]	Military jet (<3000 ft [<914m])	No response / minor behavioural changes	S/3
[625]	Simulated and actual F-16 low-altitude jet aircraft noise levels between 92-112 dB	All animals became habituated to sounds of low-altitude aircraft, and although heart rates increased during overflights they returned to resting rates in less than 2 minutes.	S/4
[626]	Repeated approaches from all-terrain vehicles	Immediate behavioural responses and decreased reproductive success (1 fawn total for N=5 females)	S/3
[627]	Snowmobiles/people on snowshoes	Stronger response to people approaching on snowshoes than slow-moving snowmobiles. Deer approached by snowshoers estimated to expend 3% of their normal daily energy expenditure in each flight	S/3
White-tailed deer (*Odocoileus virqinianus*) [581]	Snowmobile noise (35-95 dB(A))	Neither the noise nor the presence of snowmobiles caused deer to leave the areas that they normally inhabited. However, the presence of snowmobiles increased animal movements (and hence their energy expenditure) within and near their home ranges.	S/4
Elk [628]	Military jet (5000ft [1524m]), helicopter (100-500ft [31-152m])	Accelerated heart rate	S/3
[144]	250m from road traffic	Avoid the area	S/3
[629]	Simulated mine noises	Cows and calves withdrew from previously favourable areas to more marginal areas	S/3
Moose [201]	Small fixed-wing aircraft at <61m AGL	No detectable response from 7 of 17 animals; mild response from 7; 2 reacted strongly by running from aircraft. Reactions decreased from 56-37% when altitude increased from <61m to 61-183m AGL. No visible reactions to overflights >183m.	S/3
[630]	Light fixed wing aircraft	More likely to react by running when exposure is in open habitats	S/3

		rather than forest	
631,632	Pipeline/maintenance activities	No effect on movements, distribution and habitat use	O/3
508	Oil drilling rig	Continued to use habitats within 1 km of rig	O/3
Reindeer (*Rangifer tarandus*) 633	36 sonic booms (varying from 35–702 Pa [125-151 dB]) for 3 days	Slight startle responses, raising of head, pricking the ears and scenting the air. No panic reactions	S/4
634	Fixed-wing (<100ft [<31m]), helicopter (<100ft [<31m])	Crowd together, panic	M/3
Caribou (*Rangifer arcticus*) 96	Low–altitude aircraft (<200ft [<61m]) fixed wing, helicopter	Running and panic behaviour. Reaction decreased with increasing height, with no panic response for aircraft >500 ft [>152m]	M/3
	Fairchild-Hiller 1100 helicopter	Stronger responses occurred during low rather than high flights.	S/3
202	Fixed wing aircraft and helicopter <500 ft [<152m]	Fixed wing aircraft caused escape or strong panic reactions in 65-75% of groups whereas helicopter only 10-25%. Reactions during the calving season were stronger than during spring and fall migrations. Recommended flying at minimum altitude of 500 ft [152m] during summer and fall migrations and 1,000 ft [305m] at other times.	M/3
635	Low-level jet aircraft (mean height 120m AGL/maximum noise level 98.7 dB(A))	No reaction to 78% of overflights; avoidance movement in only 2%. Herd regularly exposed to military training flights therefore likelihood of habituation.	S/4
199	Low-level jet aircraft	Overflights at 30m AGL and within 50m of animals elicited more frequent and stronger responses than aircraft at 300m AGL/>75m from animals	S/3
636	Helicopter (980ft [299m])	Walk, trot or gallop away / momentarily stop feeding	S/3
637	Helicopter (<790ft [<241m]), fixed wing (<790ft [<241m])	Panic and escape	M/3
638	Long-term military training including low-level flying (35 years)	No abandonment of traditional areas or changes to home ranges	S/3
639,640	Military overflights – 1) average of 38/day at or below 1,500m AGL at 76-110 dB, + 2.4 sonic booms/day; 2) average of 4.9/day at 915-1,500m AGL at 77-104 dB.	No alteration to the pattern of seasonal habitat use within military areas	S/4
215	Fixed-wing (<1300ft [<396m]), helicopter (<1300ft [<396m])	Minor changes in behaviour/panic and run	S/3
215	Circling helicopter (Bell 206B at<400m AGL)	Responded more strongly to the circling helicopter than to simple overflights.	S/3
176	Low-level sub-sonic overflights by A-10, F-15 and F-16. The mean altitude of 161 overflights was 175m,	Approximately 76% showed some degree of overt behavioural reaction to the aircraft, but only 30% of the overflights caused the animals to move and their mean displacement only amounted to 25m.	S/5

	and the estimated mean A-weighted SEL for the caribou during all overflights was 98.5 dB(A) (maximum 122 dB(A)).	Mean duration of reaction to evaluate the disturbance was 20 seconds but animals then resumed an undisturbed activity (e.g. feeding).	
[201]	Simulated noise and frequencies of turbine engines in a gas compressor station	Generally avoid passing within 200m of sound source	S/3
[641]	General noise	Increased incidence of miscarriages; lower birth rates	M/3
Wood caribou[642]	Multiple noise disturbances due to petroleum exploration	Sufficient numbers of disturbances exceeded levels that would cause winter mass loss >20%, which could impact survival of individuals and populations.	M/3
Caribou calves [199]	Low-level overflights of military jet aircraft	Survival was negatively correlated to degree of experimenter-controlled exposure.	S/3
Pronghorn (*Antilocarpa americana*) [643]	Helicopters at 400 ft [122m] and a slant distance of 3,000 ft [914m]	No reactions. Mild reactions (muscle tensing and interruption of grazing) were observed as helicopter moved towards herd at a descent rate of 200 ft/min [61 m/min or 1 m/s] at 40-50 knots [46-58 mph or 74-93 kph]	S/3
	Helicopters at 150ft [46m] and slant distance of 500 ft [152m]	Strong reaction – running. No reaction at 60 dB(A), strong reaction at 77 dB(A)	S/4
	Fixed-wing aircraft (500 ft [152m])	Accelerated heart rate	S/3
	Military Jet (500 ft [152m])	Run short distance	S/3
	Helicopter (100 ft [30m])	Bolt and run	M/3
	Helicopter (150-400 ft [46-122m])	Stopped feeding/muscles tense/run	S/3
[197]	Sonic booms from military/ small jet aircraft	Jumping and running response to intense sonic booms	M/4
[644]	Military noise and aircraft overflights	Adults exhibited no abnormal behaviour following noise disturbance. Animals habituated to stimuli.	S/3
Livestock [645]	Sonic booms 80 – 370 mN/m^2 [0.08-0.37 Pa/72-85 dB]; low altitude subsonic flights 50 – 200m	Startle reactions	S/4
Cattle [183]	Low level overflights by fixed wing aircraft (Fiat G91, F104 g (Starfighter), F4 f (Phantom), ALPHA jet and A10 (Warthog)) and three helicopters (Alouette II, BO105 and Bell UH1D).	Group showed some general unquietness but no panic flight movements were observed; a second group moved as a unified group, which resulted in animals at the periphery being pushed against the fences. The cattle continued to show orientation behaviour after departure of the aircraft. In the case of a group of cattle mostly tied within a stable, the fixed animals were strongly excited by the low level overflights of fixed-wing aircraft.	S/3
Cattle and sheep [646]	28 sonic booms (80–370 Pa [132-145	No adverse effects were observed and behavioural responses were	S/4

	dB]) and 10 low-altitude (50-200 m AGL) subsonic flights in 4 days. Noise levels from 75-109 dB(A).	minimal. Cattle were less disturbed than sheep and species were more tolerant towards the end of the test period. Observed reactions (e.g. backward jumping) thought to be more dangerous to tied-up animals and that the effects of disturbances might be more severe for animals under certain physiological conditions such as gestation.	
Dairy cow [647]	Exploding paper bags	Cessation of milk ejection	S/3
[109]	General noise 105 dB continuous exposure	Reduced feed consumption, milk yield and rate of milk release	S/4
[108]	Simulated sonic booms	No effect on eating patterns or feed intake	O/3
[109]	Noise levels of 80 dB	Increased feed intake but no effect on the milk yield. (normal ambient noise level was 50-60 dB)	S/4
	Sudden high intensity noise (105 dB)	Reduced feed consumption, milk yield and rate of milk release	S/4
[648]	General noise (105 dB)	Increase in glycemia, nonesterified fatty acids, creatin; decrease in haemoglobin and thyroxin concentration	S/4
	Tractor engine sound 97 dB	Increased glucose concentration and leukocyte counts in the blood: reduced level of haemoglobin	S/4
	Tone of 1,000 Hz, 110 dB	Increased blood glucose (response to stress), nonesterified fatty acids and creatin; decrease in haemoglobin	S/4
[214]	Low altitude flights	Pregnant dairy cows did not run or injure themselves, nor was there any indication of reproductive problems. However, the overflights did produce vigorous behavioural, heart rate and glucocorticoid increases.	S/3
Pregnant Charollais Cows [649]	20 simulated sonic booms in 1st month	Calves were born normally	O/3
Bulls [649]	Exposed to simulated sonic booms	Had no effect on semen quality or quantity	O/3
Buffalo (*Bison bison*) [650]	F-105 overflights – L_{Amax}<90 dB	Appeared oblivious	O/4
Bison [651]	Fixed-wing (200-490ft [61-149m])	No response or run 1 mile [1.6 km] or run 5 miles [8 km]	M/3
Muskoxen [215]	Circling helicopter (Bell 206B at<400m AGL)	Responded more strongly to the circling helicopter than to simple overflights.	S/3
Sheep [652]	White noise 100 dB	Higher heart rate and respiration rate, lower feeding efficiency	S/4
	General noise 4 kHz, 100 dB	Increased number of corpora lutea; more lambs/ewe	S/4
[653]	White noise 90 dB	Decreased thyroid activity	S/4
[106, 107]	Helicopter overflights	2 to 3.5 increase in heart rate requiring a recovery time of 20-65 seconds	S/3
[654]	Noise at 75 and 100 dB	Animals ate less when exposed to noise above background levels	M/4
Lambs [63]	White noise and instrumental music (continuous) and intermittent miscellaneous sounds IMS (engines,	Intensity of sound significantly affected growth rate in early weaned lambs; music was least stressful; daily growth rate showed acclimation to sound; all nonacclimated lambs exposed to 100 dB noise gained	S/4

	aircraft, crowds, firecrackers, guns, rain, marching bands) at 75 and 100dB	significantly less weight than lambs previously exposed to 75 dB noise. Colour change was apparent in the meat of lambs exposed to white noise and IMS noise, indicating these sound types were more stressful – white noise caused more blue colour; music at 100 dB resulted in a a brighter colour.	
Bighorn sheep [628]	Military jet (<3000ft [<914m]), fixed wing aircraft (100ft [30m]), helicopter (100ft [30m])	Accelerated heart rate	S/3
[106]	Helicopter (1640-4920ft [500-1500m])	No response	O/3
	Helicopter (490-660ft [149-201m])	Accelerated heart rate, run	S/3
[513]	Military jet (<3000ft [<914m])	No response or minor behavioural changes or leave area	S/3
[655]	Helicopter (160-650ft [49-198m])	Leave area	M/3
[216, 217]	Recreational helicopter overflights	Foraging efficiency decreased by approximately 17% + a 50% increase in number of steps taken during 5-minute foraging bouts. However, the magnitude of the effect and the interaction with the altitude of the sheep varied strongly according to season. A 14% reduction in foraging efficiency reported for bighorn at 300-430m below helicopters but no significant change at 430-700m below.	M/3
[656]	Fixed-wing aircraft (100-990ft [30-302m])	No response or interrupt normal activities or run <330 feet [<101m] or run 0.62-1.2 miles [1-2 km]	S/3
[106]	Humans on foot, vehicles on a road, low-flying fixed-wing aircraft, and helicopters at dist. of 0.5 to 1.5 km.	Little change in the animal's heart rate. However, a single sheep exhibited increased heart rate (3.5 times normal) and began to run when a Bell 206 helicopter flew directly overhead at 150-200m AGL.	S/3
[629]	Helicopters	Moved 2.5 farther the day following a helicopter survey than previously. Also, 35-52% changed home range compared to 11% prior to survey. Some animals left study area.	M/3
Desert Bighorn Sheep (*Ovis canadensis nelsoni*) [192]	F-16 overflights	Aircraft overflights did not have any adverse affect on the animals' heart rates and behaviour.	O/3
[197]	Military/ small jet/ large jet/ helicopter	Declined population, during extensive and intensive aircraft operations	M/3
Mountain sheep (*Ovis canadensis mexicana*) [191]	Simulated and actual F-16 low-altitude jet aircraft noise levels between 92-112 dB	All animals became habituated to sounds of low-altitude aircraft, and although heart rates increased during overflights they returned to resting rates in less than 2 minutes.	S/4
[107]	Aircraft overflights and vehicular traffic within 200-400 m	Increased heart rates. Helicopter overflights elicited a 2-3.5 increase to heart rate, with recovery times of 20-65 seconds	S/3
Dall sheep [209]	Fairchild-Hiller 1100 helicopter flying at a distance of about 100-	Reactions were independent of whether the helicopter was above, level or below the sheep. Ewes with lambs reacted more strongly than	S/3

	150m	rams.	
Goat [657]	Jet noise	Reduced milk yield	S/3
Antelope [197]	Low altitude jet aircraft	Panic running behaviour	M/3

Conversions:
1 foot = 0.3048 metre
1 mile = 1.609 km
1 knot = 1.15 mph = 0.51 m/s = 1.84 kph
Mach 1.0 = speed of sound in air (344 m/s at 21°C)
1 N/m^2 = 1 Pa
1 psi = 6.895 Pa
1 psf = 47.88 Pa
1 atmosphere = 1.013×10^5 Pa
1 bar = 10^5 Pa
Sound pressure level = $20 \times \log_{10}(Pa/20 \times 10^{-6})$ dB

Note: Animal responses are coded using, firstly, the assessment criteria definitions of Table 5.1, i.e. 0=no effect, S=slight, M=moderate and SV=severe, and secondly, the credibility ratings of Table 5.6, i.e. 1=none, 2=low, 3=medium, 4=high , and 5=maximum.

FARM ANIMALS

Animal	Noise Source	Response	Code
Ostrich (*Struthio camelus*), Emu (*Dromaius novaehollandiae*) and Greater Rhea (*Rhea americana*)	Aircraft overflights of more than 2,000 birds in the US. Overflights included UH-1 helicopter at a range greater than 3,000 ft [914m] and a UH-60A helicopter	19 fatalities or a loss rate of 1% of exposed birds. In addition, 7 cases of breeding declines and 2 cases of stress were reported. Further data relating to the responses of more than 3352 birds provided evidence of 3 mortalities at two farms, a leg injury at one, and minor injuries at two others, i.e. a loss rate of 0.2% including injuries. The greatest incidence of risky behaviours was highest when aircraft were directly overhead and at low altitudes.	SV/3
Domestic Chicken	Simulated sonic booms 156.3 dB	Decrease in weight of 19 day old chicks	S/4
	General noise 100 dB	Increase in 11–hydrocorticosteroid in blood plasma	S/1
	Aircraft noise (3 or more days)	Reduced egg production by keeping hens from feed and water due to noise stress	M/3
	Aircraft flyover noise at 80 to 115 dB at 300 to 600 Hz	No difference in weight gain, feeding efficiency, meat tenderness or yield, or mortality between exposed and control chicks.	O/5
	Aircraft flyovers (96 dB in incubators)	No measurable effect on hatchability or quality of chicks. Sound intensities of 115 dB were effective in interrupting brooding.	O/5
Chickens	Overflights by F4 f Phantoms,	5-7 day old chicks inside light shelters climbed on top of each other though phenomenon diminished over three days of overflying. 3-5 week old chickens showed only orientation behaviour and undirected locomotions, whereas laying hens showed orientation behaviour on the first two days only, with diminishing reactions and even sleeping on the third day.	S/3
	Overflights by a hovering BO105 helicopter	Elicited greater responses than for fixed wind overflights.	S/3
Turkeys	Aircraft overflights	Habituated very rapidly, and turkeys exposed to chronic worst-case aircraft overflight noise were found to grow at the same rate as control animals although they had some behavioural differences and were found to be more difficult to handle.	S/3

	Low-level jet aircraft noise, 110-135 dB	No decrease in egg laying	O/4
Livestock	Sonic booms 80 – 370 mN/m^2 [0.08-0.37 Pa/72-85 dB]; low altitude subsonic flights 50 – 200m	Startle reactions	S/4
Farm animals	simulated sonic booms (an air overpressure of 200 N/m^2 [200 Pa/140 dB])	Startle response but eating patterns and feed intake were unaffected	S/4
Farm-raised mink (*Mustela vison*)	3 sonic booms (average 294 N/m^2 [294 Pa/143 dB])/3 simulated sonic booms (average 167 N/m^2) [167 Pa/138 dB]) - structural vibrations of 10 m/s^2 or less	Brief startle reaction, no long term effect on health and well-being of females and new born kits. Most mink returned to pre-boom activity within 2 minutes.	S/4
	Sonic booms	Female mink with kits may be alerted, pause in activity and look for the source of the noise; sleeping females may awaken; mating pairs may show momentary alertness but otherwise no disturbance; - no wounding, killing, carrying, or burying of kits in nests was observed in response to sonic booms. Reactions of mink to barking dogs, truck noises and mine blasting similar to the reactions to sonic booms.	S/3
	Jet aircraft and helicopter overflights	Straight ahead overflights by both fixed-wing aircraft and also helicopters caused lesser responses than hovering helicopters that produced quite short but stronger responses.	S/3
	Aircraft noise	Little response to fixed and rotary-winged (BO 105) noise in the absence of visual cues. When the noise event was coupled with a visual stimulus, i.e. the aircraft could be seen by the mink, the animals oriented towards the stimulus.	S/3
Horses	Low level overflights by fixed wing aircraft (Fiat G91, F104 g (Starfighter), F4 f (Phantom), ALPHA jet and A10 (Warthog)) and three helicopters (Alouette II, BO105 and Bell UH1D).	Group of horses in a large paddock showed very intensive flight reactions along the fences or random movements within the paddock, especially when the aircraft could be seen approaching. The fences were never broken or passed, but occasional biting or biting-threats as well as kicking or kicking-threats were observed. The visible excitement did not last for longer than 2 minutes.	S/3
Mares (pregnant)	Aircraft noise	All exposed mares delivered live normal foals without assistance. However, exposed mares did show significant differences in the level of anxiety and movement compared to control animals, and their heart rates increased during noise events, but no injuries occurred and no ectopic arrythymias were observed. Overall, some behavioural and physiological adaptation to the noise events was observed.	S/3

Pigs	120 dB for 6 hours	Increase of plasma 11–OH–corticosterone and catecholamines	S/4
	Engine noise, 108 dB for 72 hours	Decreased corticosteroid level, immediately followed by an increase after stimulation ceased. Biphasic response gave negative feedback effect on anterior pituitary, responsible for releasing ACTH which activates adrenals during stress. Sound exposure at least short term, influences several hormone systems in pigs	S/4
	Recorded aircraft noise (propeller/jet) 100-120 dB	No impact on conception rate or weaning	O/4
Pigs (pregnant sows in stables and open pasture)	Low level overflights by fixed wing aircraft (Fiat G91, F104 g (Starfighter), F4 f (Phantom), ALPHA jet and A10 (Warthog)) and three helicopters (Alouette II, BO105 and Bell UH1D).	Some intensified wagging of tails, but even when 'chased' by helicopters at a height of only 5m the pigs exhibited only slow trotting action for brief periods.	S/3
Castrated Male Pigs	93 dB (unspecified frequency)	Excess secretion of hormones, water retention and sodium retention. Also , excess aldosterone may be induced by stress, resulting in the upset the electrolyte balance, which can be manifested by hypertension (possibly due to sodium and water retention), excessive urination and thirst.	S/4
Swine	General noise 93dB	Aldosteronism (excess secretion of aldosterone from the adrenals)	S/4
Cattle	Low level overflights by fixed wing aircraft (Fiat G91, F104 g (Starfighter), F4 f (Phantom), ALPHA jet and A10 (Warthog)) and three helicopters (Alouette II, BO105 and Bell UH1D).	Group showed some general unquietness but no panic flight movements were observed; a second group moved as a unified group, which resulted in animals at the periphery being pushed against the fences. The cattle continued to show orientation behaviour after departure of the aircraft. In the case of a group of cattle mostly tied within a stable, the fixed animals were strongly excited by the low level overflights of fixed-wing aircraft.	S/3
Cattle [20] and sheep [18]	28 sonic booms (80–370 Pa [132-145 dB]) and 10 low-altitude (50-200 m AGL) subsonic flights in 4 days. Noise levels from 75-109 dB(A).	No adverse effects were observed and behavioural responses were minimal. Cattle were less disturbed than sheep and species were more tolerant towards the end of the test period. Observed reactions (e.g. backward jumping) thought to be more dangerous to tied-up animals and that the effects of disturbances might be more severe for animals under certain physiological conditions such as gestation.	S/4
Dairy cow	Exploding paper bags	Cessation of milk ejection	S/3
	General noise 105 dB continuous exposure	Reduced feed consumption, milk yield and rate of milk release	S/4
	Simulated sonic booms	No effect on eating patterns or feed intake	O/3
	Noise levels of 80 dB	Increased feed intake but no effect on the milk yield. (normal ambient	S/4

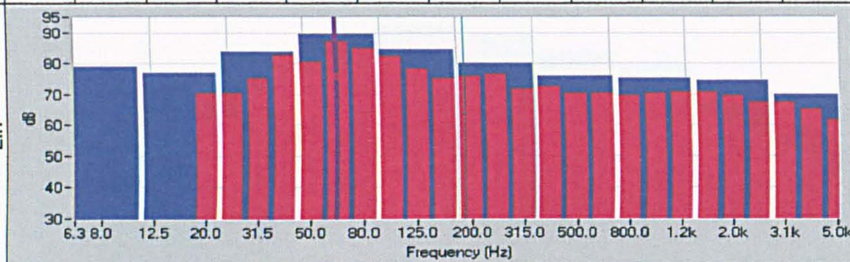
		noise level was 50-60 dB)	
	Sudden high intensity noise (105 dB)	Reduced feed consumption, milk yield and rate of milk release	S/4
	General noise (105 dB)	Increase in glycemia, nonesterified fatty acids, creatin; decrease in haemoglobin and thyroxin concentration	S/4
	Tractor engine sound 97 dB	Increased glucose concentration and leukocyte counts in the blood: reduced level of haemoglobin	S/4
	Tone of 1,000 Hz, 110 dB	Increased blood glucose (response to stress), nonesterified fatty acids and creatin; decrease in haemoglobin	S/4
	Low altitude flights	Pregnant dairy cows did not run or injure themselves, nor was there any indication of reproductive problems. However, the overflights did produce vigorous behavioural, heart rate and glucocorticoid increases.	S/3
Pregnant Charollais Cows	20 simulated sonic booms in 1st month	Calves were born normally	O/3
Bulls	Exposed to simulated sonic booms	Had no effect on semen quality or quantity	O/3
Sheep	White noise 100 dB	Higher heart rate and respiration rate, lower feeding efficiency	S/4
	White noise 90 dB	Decreased thyroid activity	S/4
	General noise 4 kHz, 100 dB	Increased number of corpora lutea; more lambs/ewe	S/4
	Helicopter overflights	2 to 3.5 increase in heart rate requiring a recovery time of 20-65 seconds	S/3
	Noise at 75 and 100 dB	Animals ate less when exposed to noise above background levels	M/4
Lambs	White noise and instrumental music (continuous) and intermittent miscellaneous sounds IMS (engines, aircraft, crowds, firecrackers, guns, rain, marching bands) at 75 and 100dB	Intensity of sound significantly affected growth rate in early weaned lambs; music was least stressful; daily growth rate showed acclimation to sound; all nonacclimated lambs exposed to 100 dB noise gained significantly less weight than lambs previously exposed to 75 dB noise. Colour change was apparent in the meat of lambs exposed to white noise and IMS noise, indicating these sound types were more stressful – white noise caused more blue colour; music at 100 dB resulted in a a brighter colour.	S/4
Goat	Jet noise	Reduced milk yield	S/3

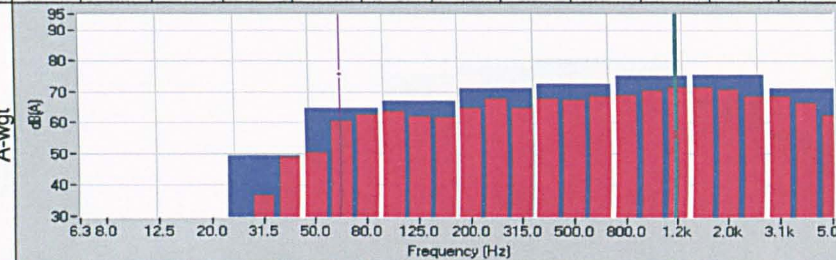
APPENDIX VII

Author's Third Octave Band Frequency Data for Various Noise Sources

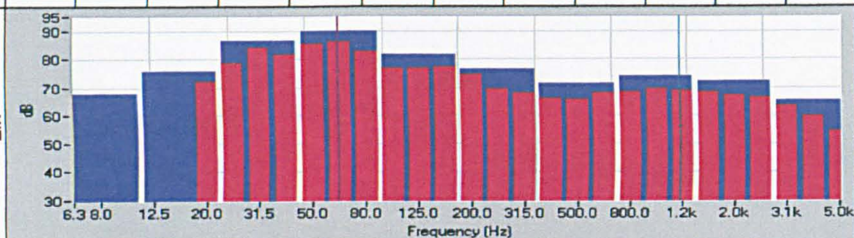
Military Explosions (Plastic Explosive) - Third Octave Band Frequency Data (Measured at 100m)

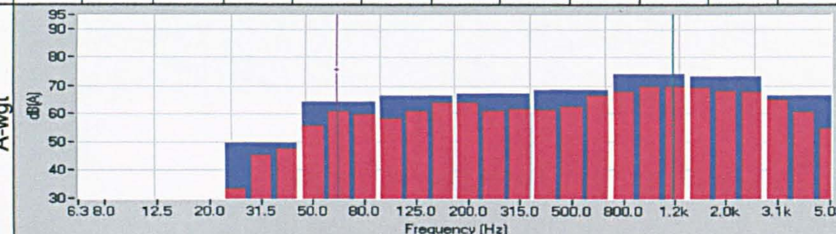
Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
1	Lin	70.43	75.17	82.79	80.44	86.91	84.98	82.34	78.3	75.03	75.93	76.58	71.75	72.44	70.4	70.16	69.62	70.17	70.71	70.62	69.63	67.4	67.36	65.27	61.65	92.5	
	A-wgt	26.38	36.57	49.03	50.22	60.39	62.86	63.61	61.79	61.63	65.01	67.81	64.97	67.6	67.27	68.35	68.79	70.15	71.3	71.58	70.82	68.66	68.55	66.24	62.26	80.7	11.8



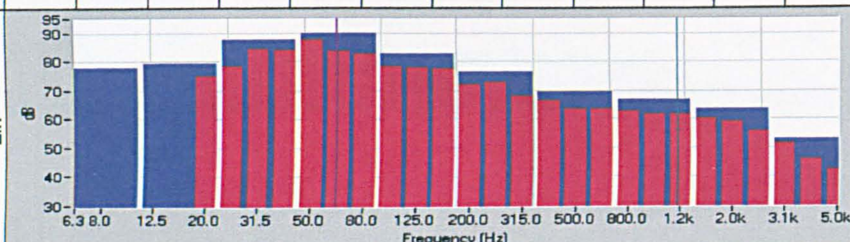


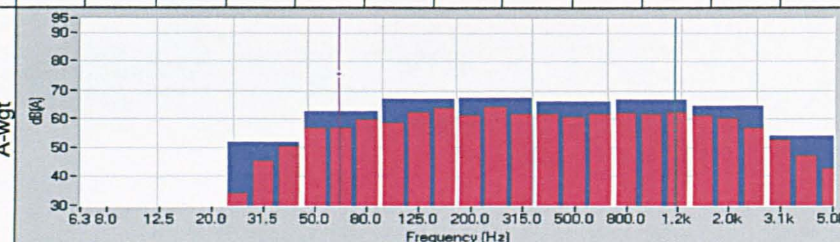
2	Lin	78.66	84.07	81.65	85.45	86.42	82.76	76.76	76.82	77.12	74.5	69.43	68.26	66.02	65.68	67.98	68.6	69.5	68.87	68.39	66.94	66.43	63.53	59.61	54.22	92.4	
	A-wgt	33.16	45.26	47.42	55.63	60.71	59.84	58.22	60.94	63.76	63.77	60.7	61.47	61.16	62.45	66.18	67.78	69.55	69.47	69.36	68.13	67.7	64.73	60.6	54.85	78.4	14





3	Lin	78.2	84.41	83.96	87.76	83.6	82.6	78.17	78.07	77.55	72.2	73.03	68.07	66.37	63.56	63.51	62.74	61.73	61.68	60.26	59.02	55.62	51.4	46.1	42.32	93	
	A-wgt	34.13	45.3	50.36	57	56.79	59.71	58.83	62.49	63.79	61.07	64.19	61.59	61.63	60.39	61.64	61.9	61.69	62.27	61.22	60.22	56.89	52.6	47.1	42.89	73.8	19.2

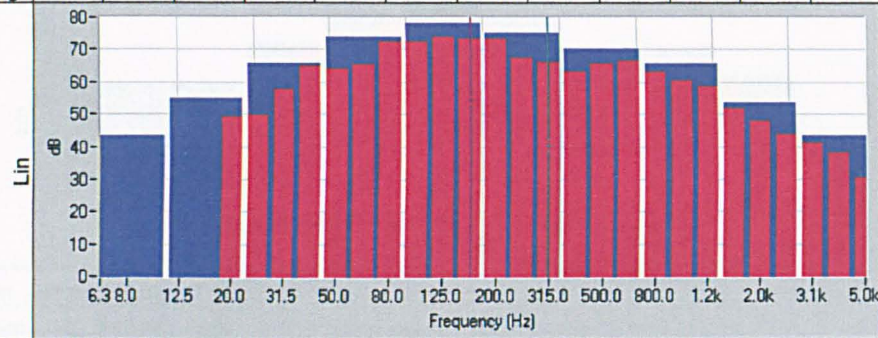


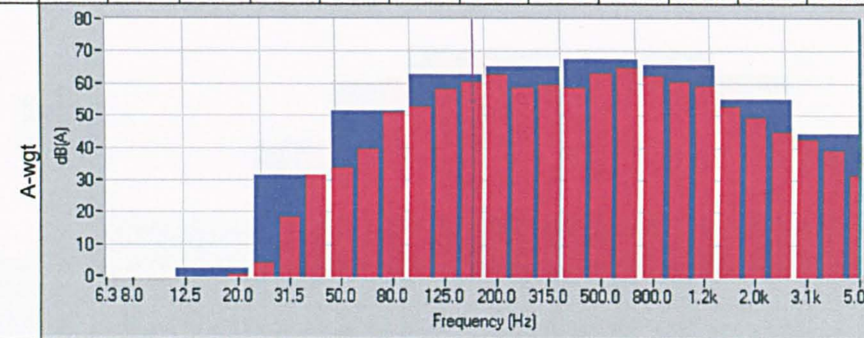


																										Avg	15.0

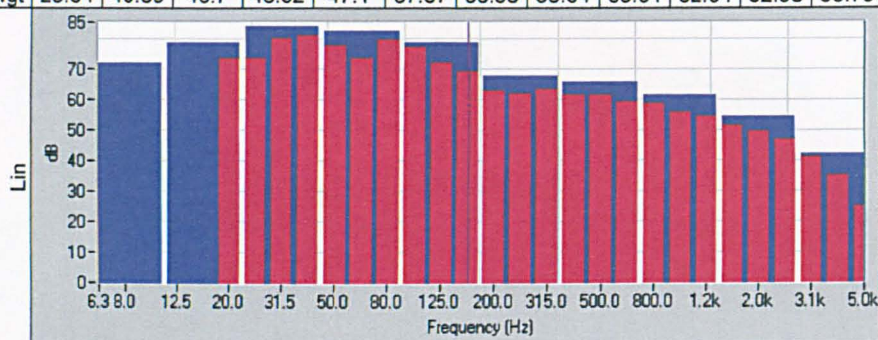
Firework Explosions - Third Octave Band Frequency Data (Measured at 2,300m)

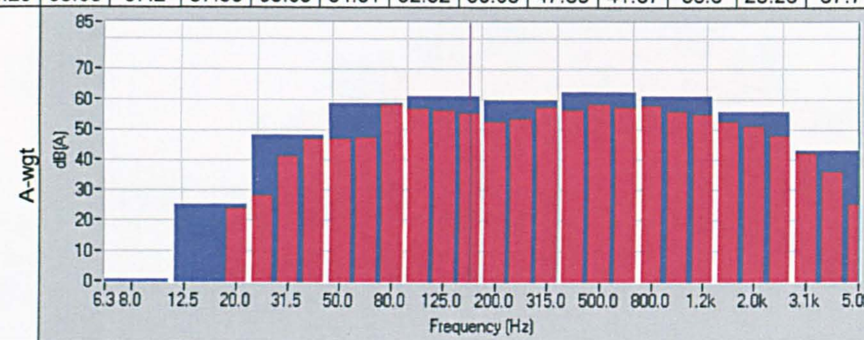
Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
1	Lin	49.8	57.8	64.82	63.86	65.13	72.39	72.6	73.9	73.44	73.47	67.6	66.08	63.04	65.88	66.63	63.16	60.37	58.5	51.84	47.84	43.59	41.28	38.04	30.54	81.4	
	A-wgt	4.22	18.15	31.1	33.32	39.22	51.08	52.77	58.25	60.16	62.52	58.7	59.31	58.52	62.81	64.6	62.3	60.36	59.05	52.76	49.01	44.85	42.49	39.03	31.22	71.7	9.7



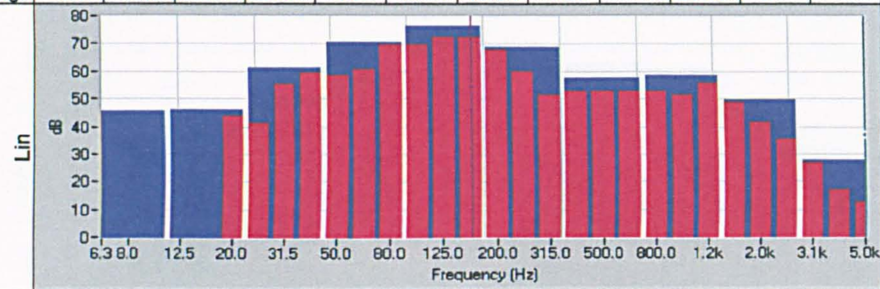


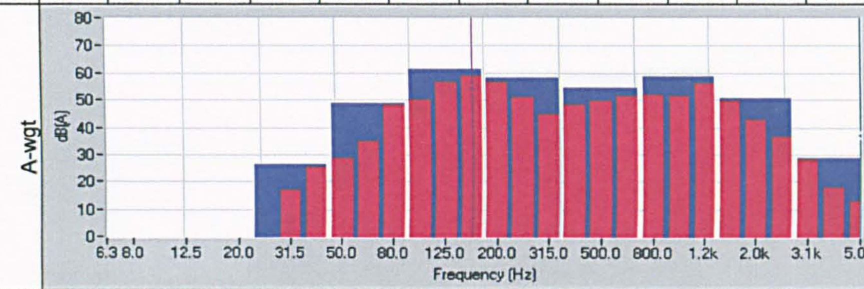
2	Lin	73.28	79.85	80.88	77.19	72.96	79.45	76.74	71.6	68.73	62.49	61.53	63.34	61.14	61.09	59.06	58.27	55.63	54.06	51.35	49.5	46.31	40.66	34.6	24.61	87	
	A-wgt	28.04	40.89	46.7	46.32	47.1	57.87	56.58	55.84	55.04	52.04	52.98	56.79	56.25	58.08	57.2	57.36	55.63	54.61	52.32	50.68	47.58	41.87	35.6	25.26	67.7	19.3



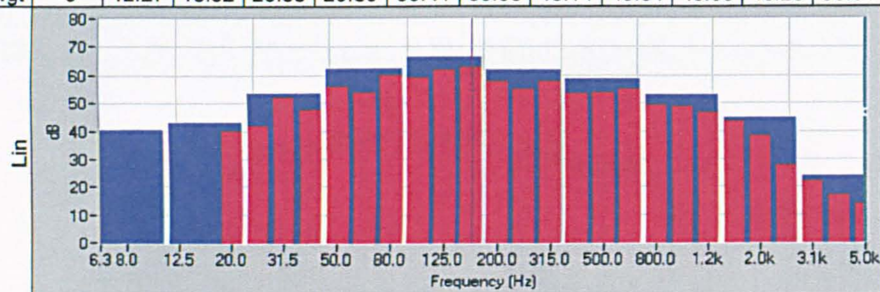


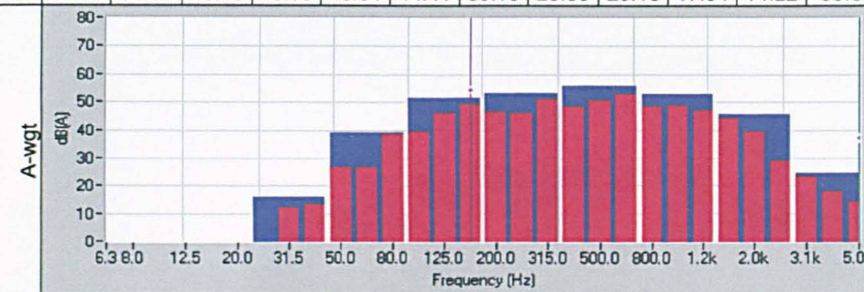
Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
3	Lin	41.12	55.57	59.64	58.77	60.78	69.9	69.75	72.23	72.56	68.07	59.87	51.27	52.89	52.75	52.84	52.81	51.28	55.84	48.8	41.6	35.2	26.99	16.79	12.45	78.2	
	A-wgt	-4.58	17.18	25.59	28.65	34.89	48.48	49.93	56.68	59.19	56.92	51	44.76	48.08	49.52	51.18	51.81	51.22	56.35	49.71	42.79	36.46	28.2	17.78	13.03	65.1	13.1



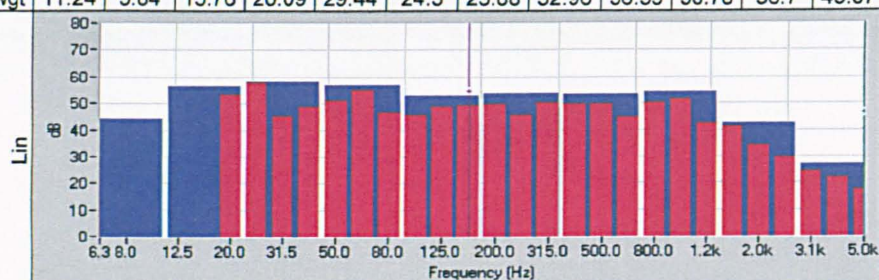


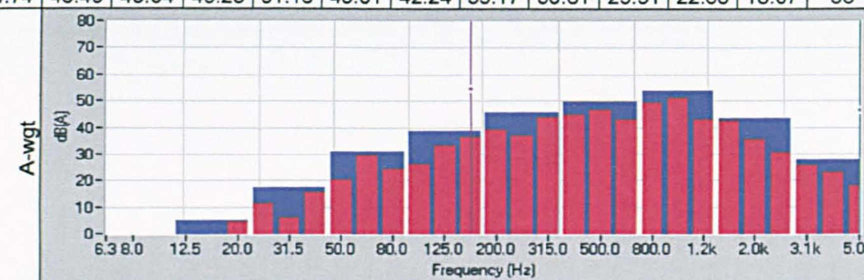
Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
4	Lin	41.54	51.69	47.54	55.84	53.5	59.85	59.06	61.82	62.73	57.68	54.8	57.52	53.12	53.56	54.87	49	48.67	46.27	43.47	38	27.7	21.97	16.85	13.64	69.3	
	A-wgt	-3	12.27	13.52	26.85	26.89	38.41	39.53	46.14	49.34	46.66	46.25	50.81	48.21	50.38	52.86	48.18	48.63	46.84	44.41	39.18	28.96	23.18	17.84	14.22	59.8	9.5



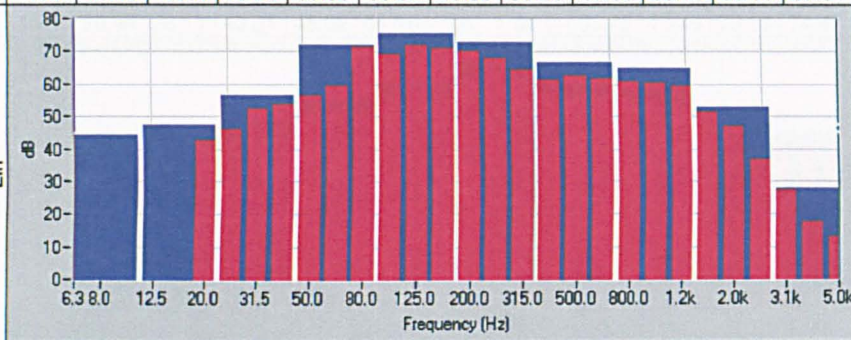


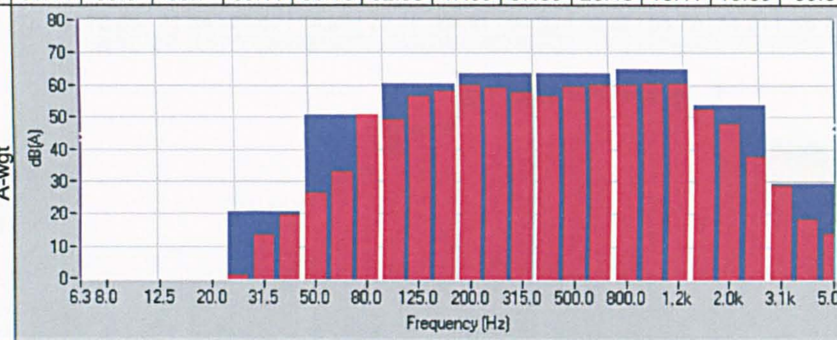
Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
5	Lin	57.49	45.18	48.91	51.08	55.17	46.27	45.7	48.58	49.32	49.51	45.49	50.11	49.6	49.73	44.86	50.01	51.21	42.47	41.29	33.98	29.34	24.31	21.7	17.46	63.6	
	A-wgt	11.24	5.84	15.76	20.09	29.44	24.3	25.88	32.96	36.35	38.78	36.7	43.87	44.74	46.49	43.04	49.23	51.16	43.01	42.24	35.17	30.61	25.51	22.68	18.07	56	7.6



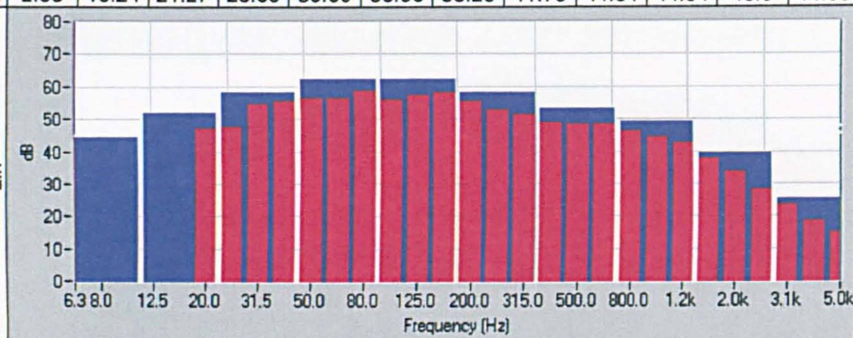


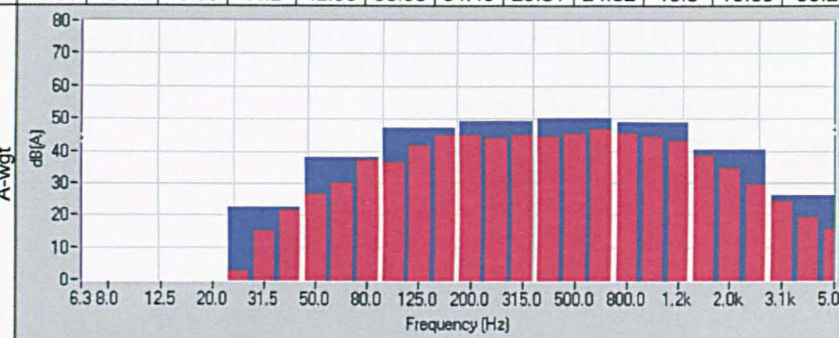
Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
6	Lin	45.9	52.12	53.82	56.31	59.44	71.42	69.07	71.87	71.04	70.33	67.77	64.25	61.01	62.53	61.78	60.59	60.14	59.63	51.44	46.82	36.43	27.26	17.4	13.1	79	
	A-wgt	1.04	13.49	19.64	26.28	33.03	50.32	49.06	56.26	57.95	59.79	58.95	57.54	56.41	59.44	59.9	59.7	60.11	60.16	52.38	47.99	37.69	28.48	18.41	13.69	69.6	9.4





Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
All	Lin	47.28	54.39	55.42	56.19	56.42	58.66	56.01	57.43	58.01	55.51	52.65	51.27	48.91	48.24	48.23	45.98	44.22	42.37	37.63	33.31	28.24	23.12	18.31	14.96	66.9	
	A-wgt	2.68	15.24	21.27	26.33	30.09	36.96	36.23	41.79	44.64	44.64	43.9	44.58	44.13	45.03	46.29	45.09	44.2	42.93	38.58	34.49	29.51	24.32	19.3	15.55	55.2	11.7

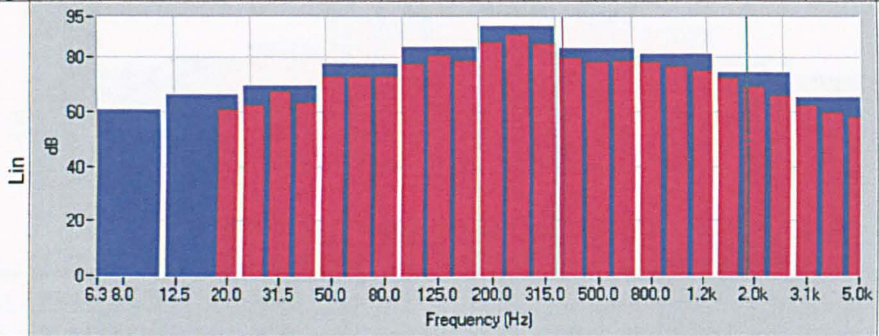


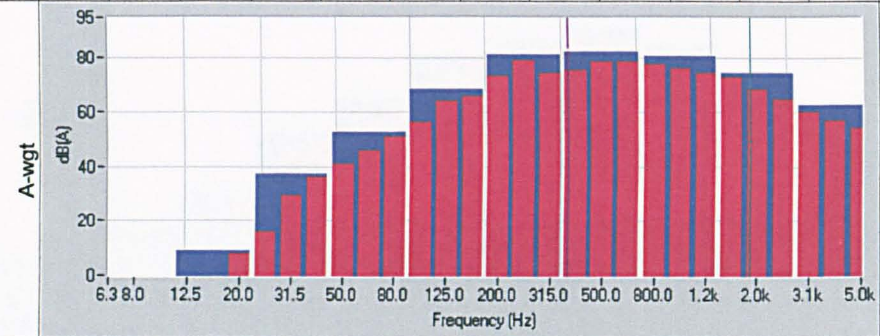


																										Avg	11.5

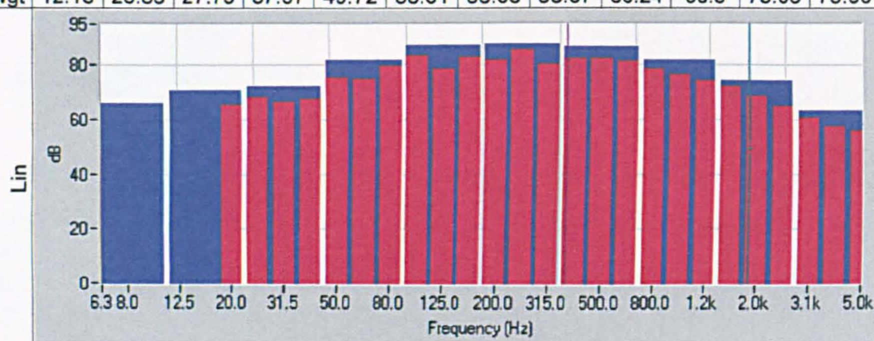
Red Arrows Low-Flying - Third Octave Band Frequency Data (Measured at <1,000m)

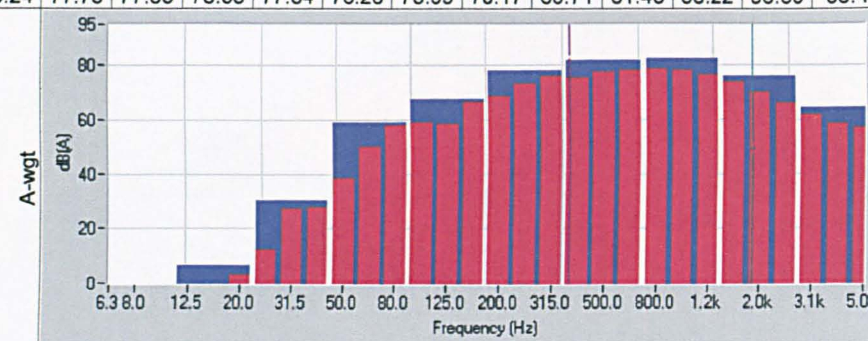
Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
1	Lin	61.91	67.27	63.06	72.72	72.5	72.73	77.28	80.86	78.44	85.53	88.25	85.06	79.73	77.87	78.48	78.14	76.43	74.85	71.92	69.03	65.76	62.36	59.4	57.68	93.1	
	A-wgt	16.1	28.96	36.11	40.61	45.52	51.16	56	64.1	65.75	73.45	79.16	74.47	75.54	78.36	78.65	77.64	75.67	74.28	72.49	68.41	64.63	60.22	56.72	54.31	86.7	6.4



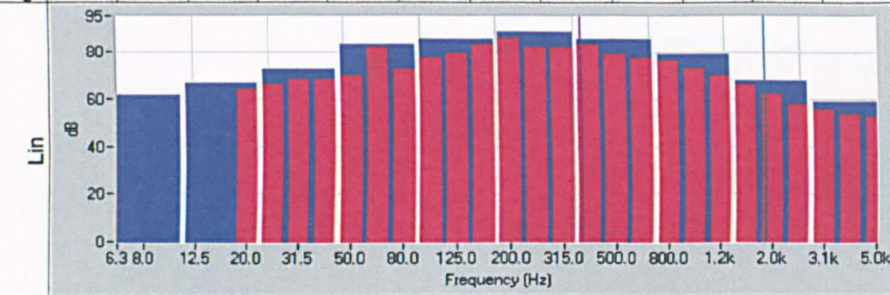


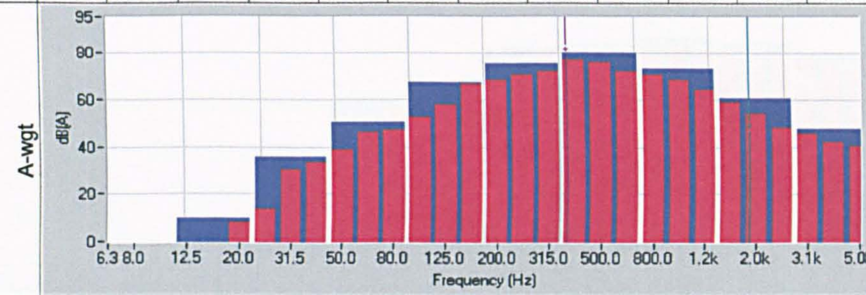
Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
2	Lin	67.81	66.42	67.39	75.21	74.93	79.4	83.37	78.31	83	81.63	85.2	80.34	82.13	82.51	81.22	78.54	76.47	74.37	72.11	68.29	64.75	60.27	57.2	55.74	93	
	A-wgt	12.18	26.85	27.75	37.97	49.72	58.01	58.88	58.57	66.24	68.5	73.05	75.96	75.24	77.73	77.83	78.33	77.84	76.26	73.59	70.17	65.71	61.43	58.22	56.53	86.4	6.6



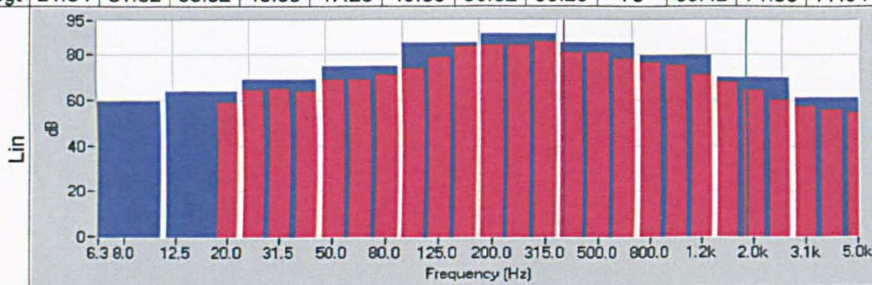


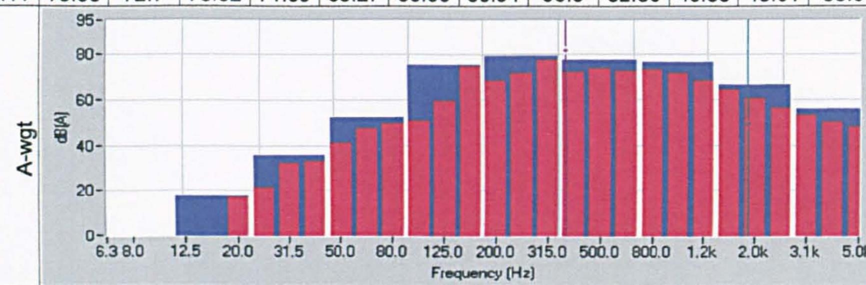
Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
3	Lin	66.09	68.54	68.44	70.01	82.51	72.53	77.29	79.46	83.33	86.08	82.06	82.11	83.15	79.16	77.67	76.63	73.37	70.29	66.2	62.33	57.93	55.56	53.53	52.44	92.4	
	A-wgt	14.02	30.29	33.61	38.67	46.38	47.5	52.33	57.58	66.93	68.32	70.82	72.27	76.86	75.78	72.03	70.45	68.64	64.44	59.12	54.04	48.14	45.6	41.89	40.2	82.2	10.2



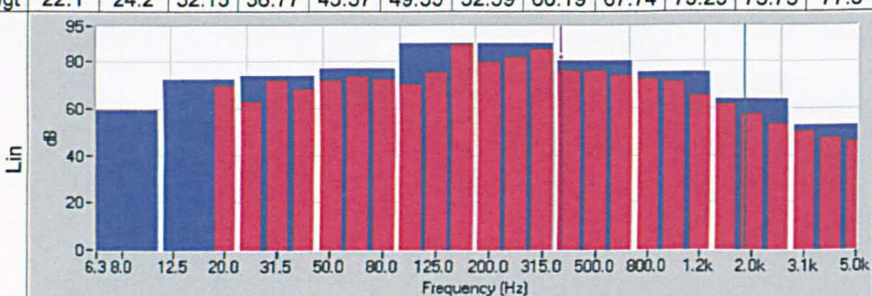


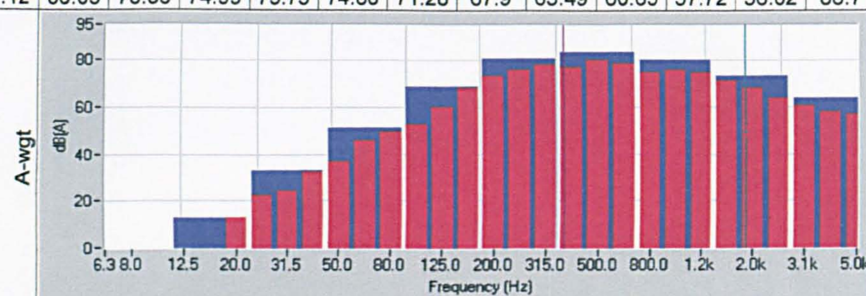
4	Lin	64.44	64.95	63.78	68.88	69.11	71.08	73.57	78.31	83.09	83.89	83.98	85.65	80.44	80.87	78.04	76.42	75.23	70.95	67.96	64.42	59.81	57.37	55.74	54.66	92	
	A-wgt	21.34	31.62	33.02	40.69	47.26	49.33	50.62	59.29	75	68.42	71.55	77.54	72.11	73.58	72.7	73.02	71.89	68.27	63.99	60.54	56.5	52.86	49.86	48.01	83.3	8.7



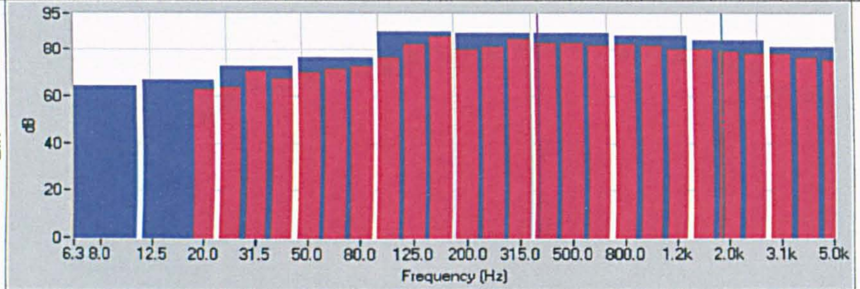


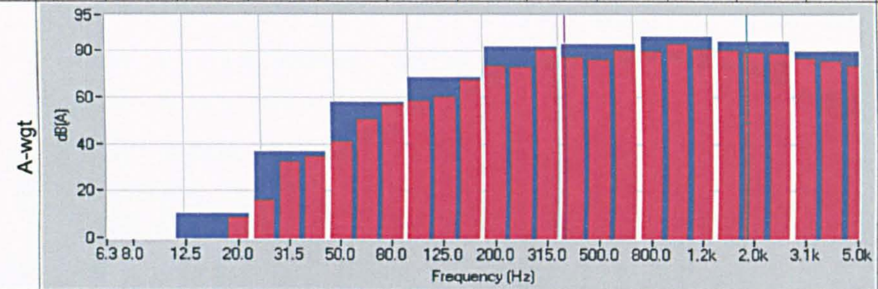
5	Lin	62.81	71.88	67.77	71.6	73.27	72.22	70.13	75.47	86.96	79.87	81.93	84.83	75.96	75.98	73.6	72.28	71.27	65.39	61.66	57.51	53.09	49.72	47.17	45.56	91.2	
	A-wgt	22.1	24.2	32.15	36.77	45.57	49.35	52.59	60.19	67.74	73.23	75.75	77.8	77.12	80.05	78.36	74.99	75.75	74.88	71.28	67.9	63.49	60.65	57.72	56.62	86.7	4.5



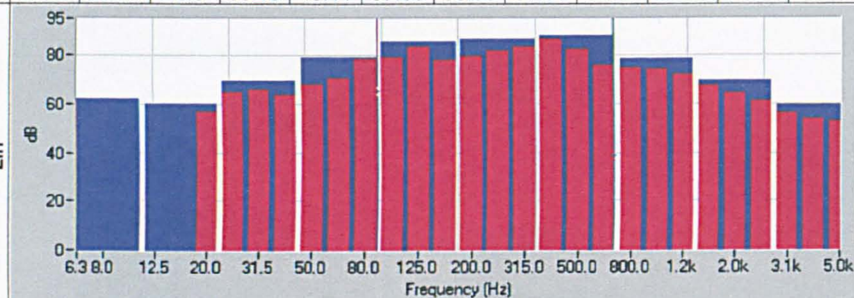


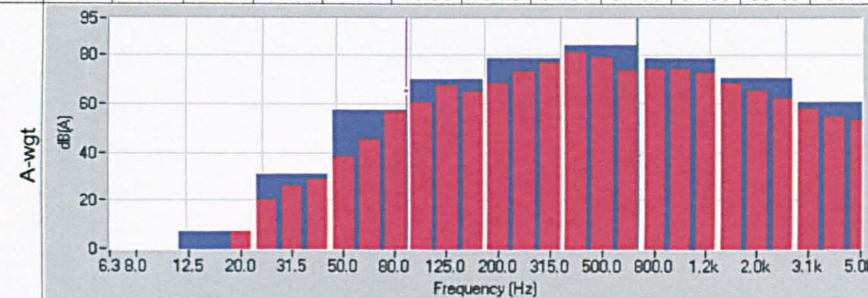
Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
6	Lin	63.44	70.71	67.59	70	71.89	72.93	76.68	82.04	85.5	80.22	81.19	84.52	82.96	82.64	81.88	82.07	81.54	80.4	80.17	79.32	78.02	77.85	76.5	75.11	94	
	A-wgt	15.72	32.46	34.6	40.89	50.17	56.94	58.55	59.96	67.51	73.08	72.84	80.65	77.15	75.96	80.31	79.47	82.98	80.61	80	78.86	78.51	76.21	75.31	73.1	90.5	3.5



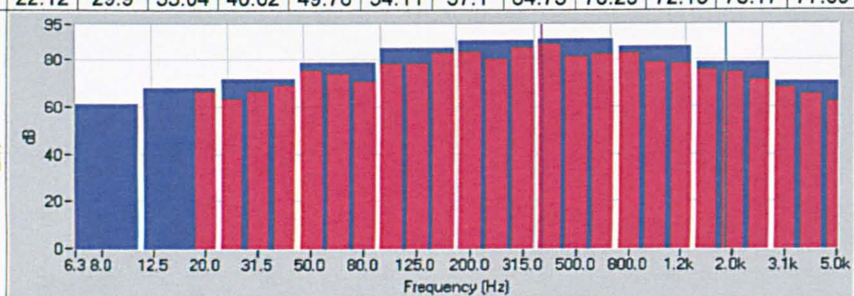


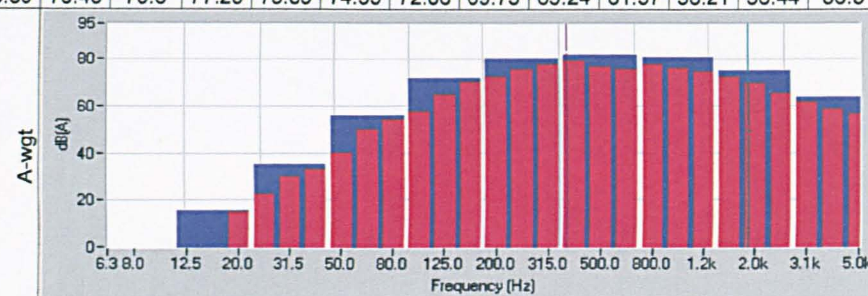
Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
7	Lin	64.66	65.69	63.69	67.67	70.46	78.31	79.29	83.29	78.17	79.57	81.62	83.54	86.37	82.35	75.71	75.02	74.12	72.23	67.6	64.04	60.81	56.39	53.71	52.53	92.2	
	A-wgt	20.13	26.08	28.6	38.13	45.11	57.05	60.68	67.61	64.51	68.54	73.28	76.75	81.32	78.87	73.82	74.18	74.11	72.75	68.58	65.23	62.08	57.59	54.69	53.09	86.1	6.1



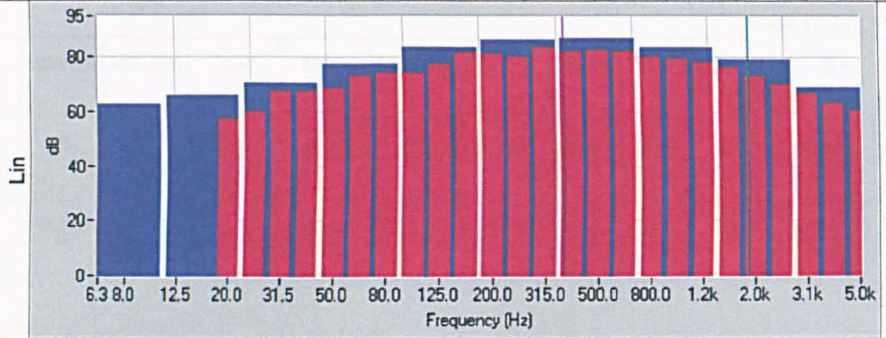


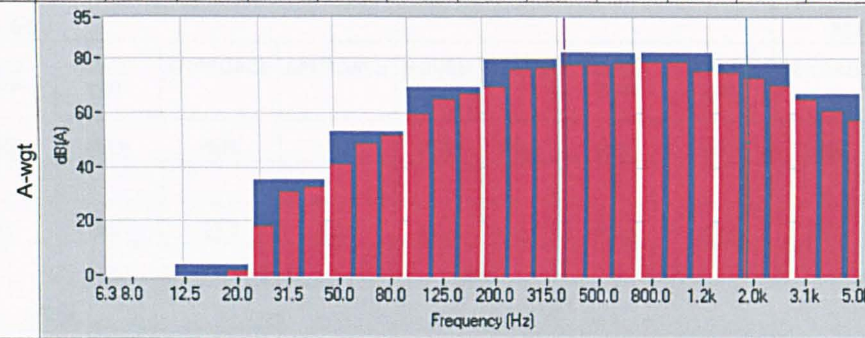
Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
8	Lin	63.37	66.26	69.13	75.48	73.53	70.41	77.8	77.94	82.83	83.24	80.02	84.83	86.25	81.33	82.4	82.99	78.57	77.89	75.21	74.22	71.03	68.1	65.13	62.16	93.4	
	A-wgt	22.12	29.9	33.04	40.02	49.76	54.11	57.1	64.73	70.23	72.13	75.17	77.69	78.85	76.45	75.6	77.25	75.85	74.53	72.06	69.73	65.24	61.37	58.21	56.44	86.3	7.1



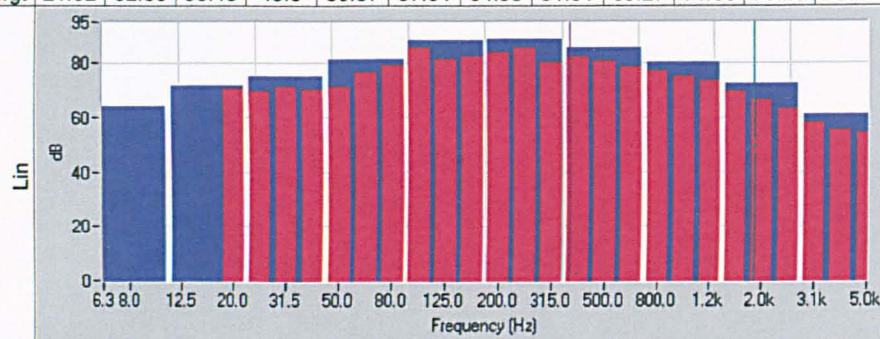


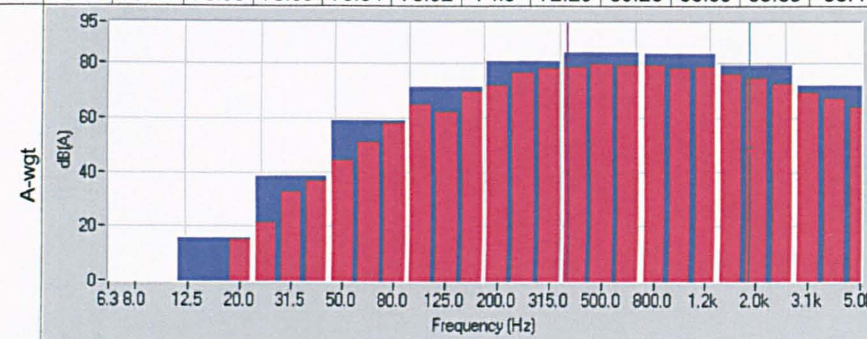
Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
9	Lin	59.95	67.58	67.22	68.44	72.99	74.19	74.21	77.46	81.82	81.24	79.98	83.73	82.14	82.67	82.27	80	79.48	78.26	76.48	73.42	70.03	66.64	62.98	60.31	92.1	
	A-wgt	17.78	31.01	32.61	40.6	48.25	51.33	59.32	64.66	66.9	69.54	75.83	76.62	77.65	77.35	77.77	78.6	78.32	75.36	75.04	72.93	69.87	64.98	60.36	57.25	87.1	5





10	Lin	69.46	71.2	69.97	71.14	76.17	79.3	85.64	81.29	82.49	83.67	85.55	80.24	82.26	80.75	78.53	76.94	74.78	73.01	69.73	66.33	62.9	58.04	55.01	53.89	93.1	
	A-wgt	21.32	32.55	36.46	43.8	50.97	57.91	64.53	61.91	69.27	71.68	76.25	78.27	78.64	79.53	79.24	78.95	78.06	78.34	75.92	74.5	72.29	69.23	66.69	63.88	88.4	4.7





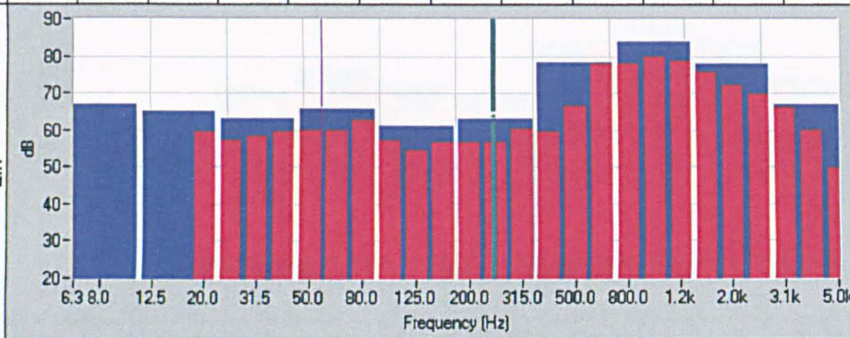
																										Avg	6.3

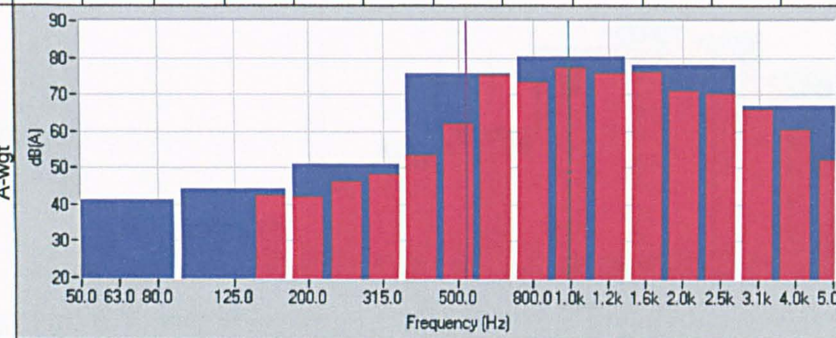
Unweighted and A-Weighted Noise Levels for Military Helicopters (measured at 130m)

	APACHE WA-64																		MERLIN	
	HOVER	HOVER	SIDE (R)	SIDE (R)	SIDE (L)	SIDE (L)	REAR	REAR	HOVER (@250m)	HOVER (@250m)	TAKE-OFF	TAKE-OFF	APPROACH	APPROACH	HOVER	HOVER	TAKE-OFF	TAKE-OFF	FLYPAST	FLYPAST
	dBL	dBA	dBL	dBA	dBL	dBA	dBL	dBA	dBL	dBA	dBL	dBA	dBL	dBA	dBL	dBA	dBL	dBA	dBL	dBA
TOTAL	88.5	73.4	83.3	60.7	85.3	67.1	87.7	65.3	82.7	62.9	81	64	85.2	63.9	85.9	61.7	83.3	59.1	86.7	62.9
Difference	15.1		22.6		18.2		22.4		19.8		17		21.3		24.2		24.2		23.8	
Average	20.9																			

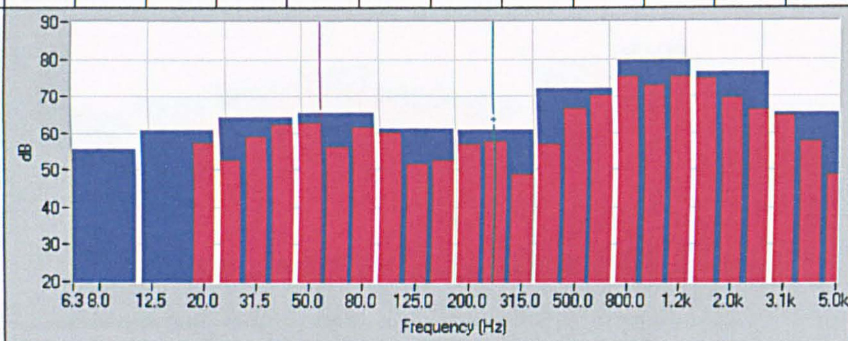
PA/Crowd Noise - Third Octave Band Frequency Data (Measured at 100m)

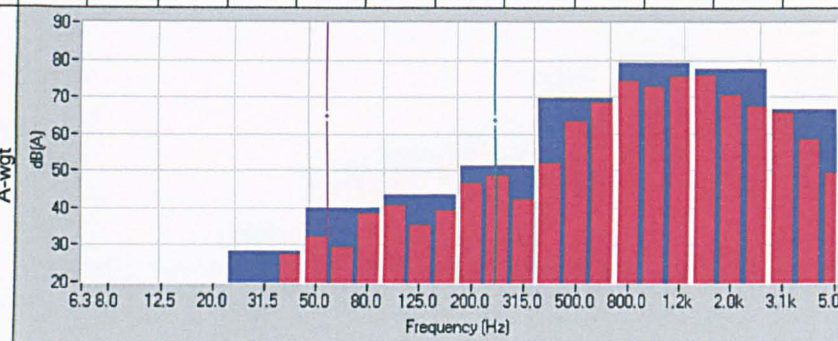
Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
1	Lin	56.98	58.42	59.5	59.79	59.71	62.48	57.07	54.59	56.71	56.76	56.7	60.17	59.37	66.6	77.97	77.94	80.02	78.74	75.68	71.85	69.64	65.99	60.03	49.85	85.8	
	A-wgt	13.31	19.44	25.5	29.84	33.15	39.37	37.84	38.98	43.43	45.68	48.07	53.7	54.63	63.51	76.19	77.09	80	79.31	76.67	73.03	70.91	67.19	61.04	50.49	85.6	0.2



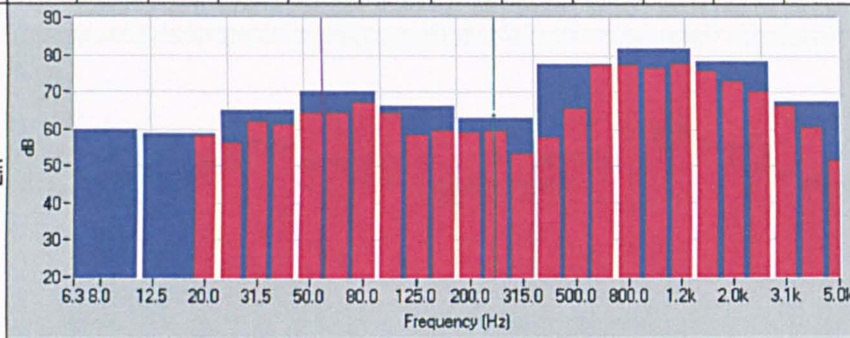


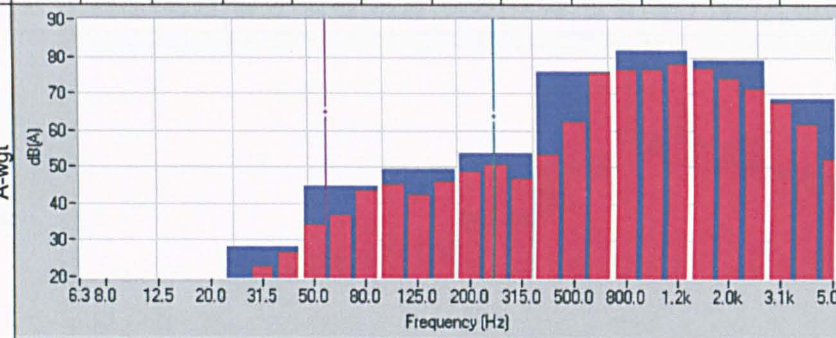
Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
2	Lin	52.28	58.56	62.23	62.58	56.12	61.34	59.84	51.4	52.6	56.95	57.45	48.65	56.58	66.57	70.11	75.2	72.8	75.16	74.86	69.41	66.07	64.57	57.48	48.6	81.9	
	A-wgt	8.74	18.83	27.6	32.18	29.47	38.52	40.71	35.36	39.04	46.58	48.48	42.23	52.13	63.35	68.53	74.3	72.68	75.71	75.79	70.61	67.33	65.78	58.46	49.25	81.8	0.1



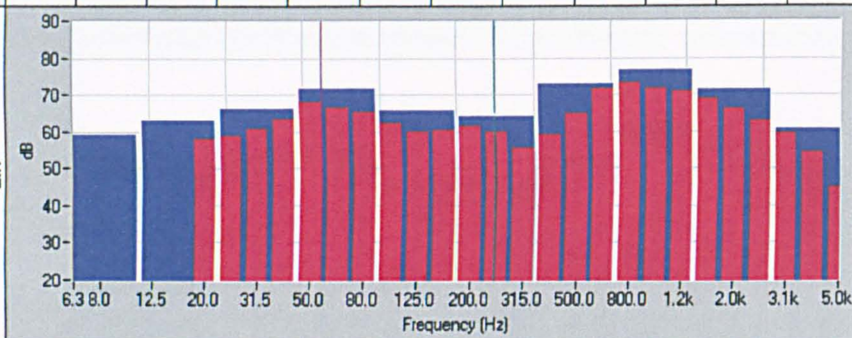


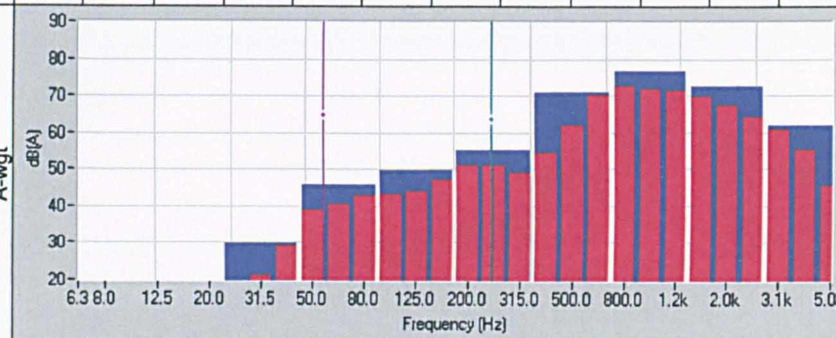
Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
3	Lin	55.9	61.94	61.18	64.24	64.01	66.75	64.1	58.35	59.33	59.16	59.48	53.15	57.6	65.46	77.25	76.99	76.35	77.39	75.61	72.83	69.93	66.2	60.3	51.33	84.7	
	A-wgt	10.7	22.8	26.46	33.91	36.87	43.53	45	42.21	45.87	48.65	50.41	46.43	53.07	62.16	75.65	76.25	76.42	77.94	76.58	74.01	71.19	67.4	61.31	51.98	84.4	0.3





4	Lin	58.82	60.74	63.37	68.15	66.39	65.47	62.23	59.87	60.34	61.53	59.72	55.54	59.09	65.05	71.64	73.33	71.63	70.86	68.83	66.15	63.02	59.59	54.36	44.91	80.3	
	A-wgt	14.27	21.15	28.95	38.68	40.23	42.77	43.03	43.81	46.99	50.94	50.94	48.96	54.59	61.93	69.91	72.49	71.61	71.42	69.79	67.33	64.28	60.79	55.36	45.55	78.9	1.4



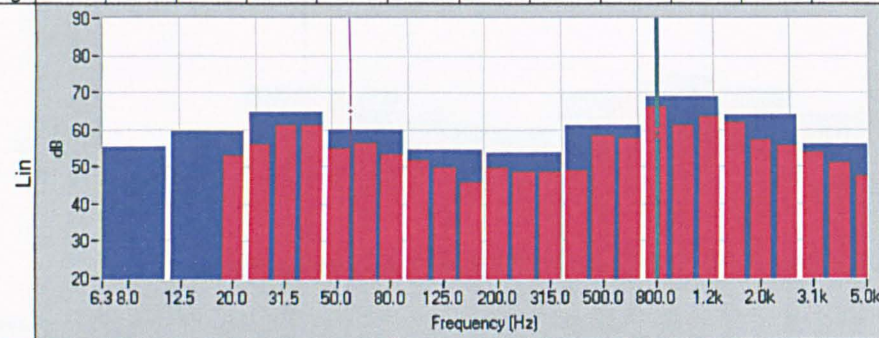


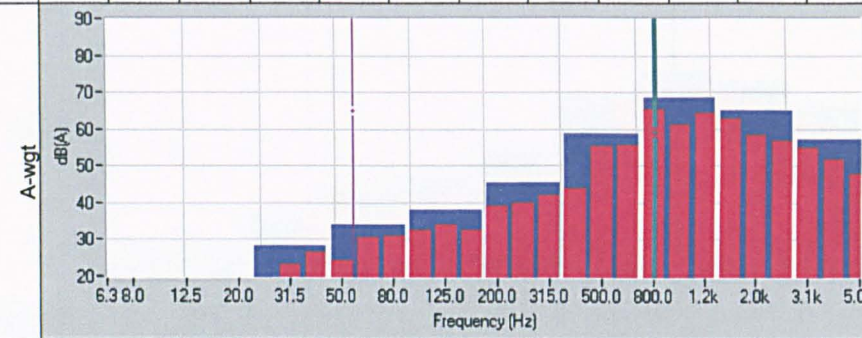
																										Avg	0.5

PA/Crowd Noise - Third Octave Band Frequency Data (Measured at 400m)

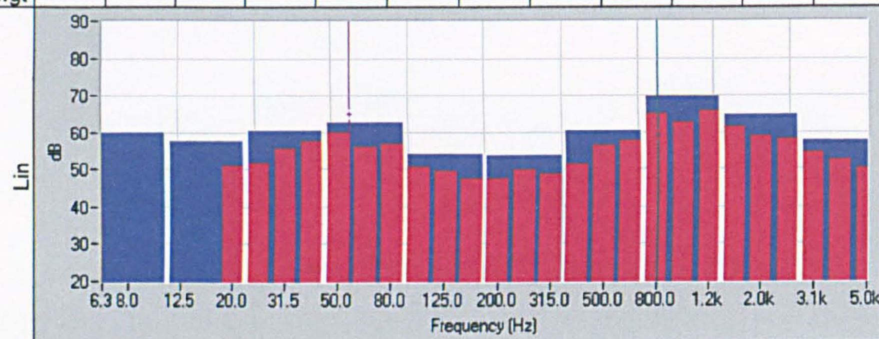
Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
1	Lin	56	60.96	61.06	54.68	56.44	53.26	51.86	49.9	45.64	49.76	48.6	48.43	48.88	58.15	57.47	66.17	61.19	63.45	61.86	57.24	55.61	53.54	50.72	47.19	72.1	
	A-wgt	11	23.21	26.6	24.18	30.65	30.97	32.57	34.08	32.33	39.04	40.04	41.98	43.98	55.33	55.66	65.29	61.22	64.02	62.82	58.42	56.88	54.74	51.7	47.77	70.6	1.5
2	Lin	51.51	55.69	57.35	60	55.98	56.79	50.56	49.3	47.37	47.25	49.7	48.7	51.21	56.28	57.47	65.15	62.75	65.77	61.35	58.88	57.89	54.48	52.61	49.93	72.2	
	A-wgt	6.78	16.38	22.98	30.24	29.45	34.19	31.64	33.31	33.94	36.51	40.84	42.12	46.53	52.93	55.68	64.26	62.6	66.4	62.3	60.07	59.16	55.67	53.59	50.52	71.4	0.8

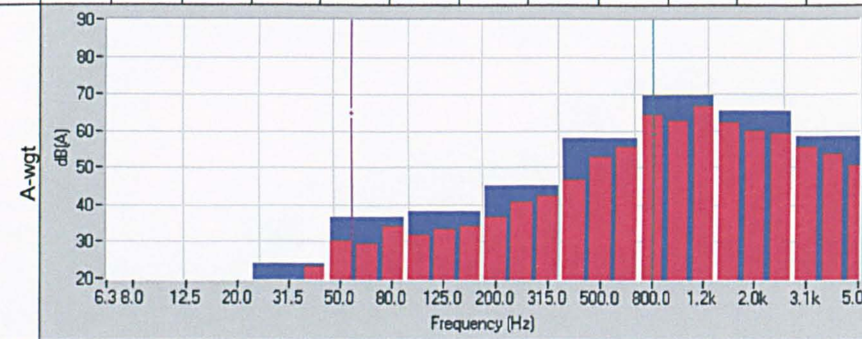
Sample 1:



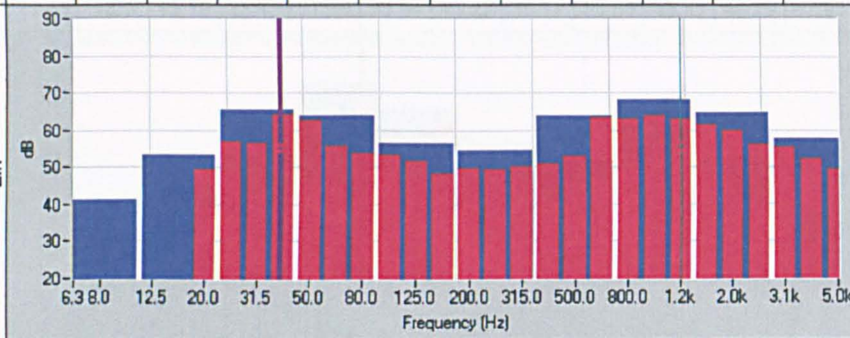


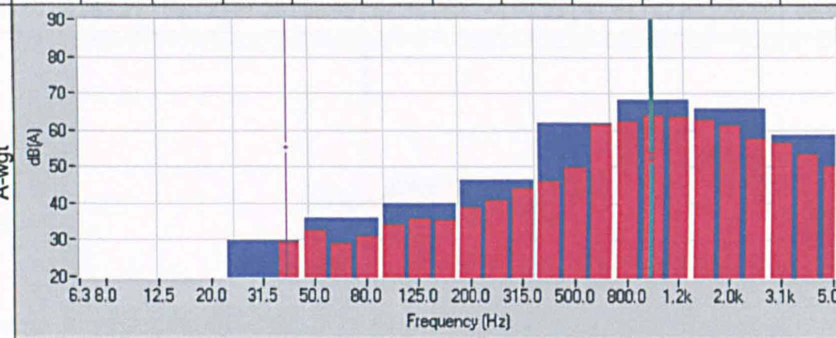
Sample 2:



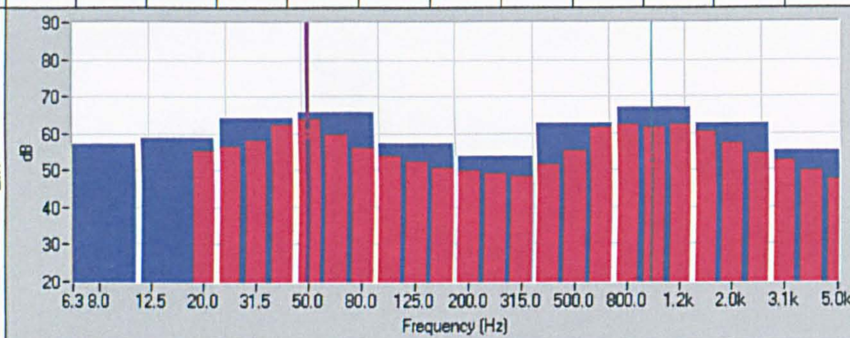


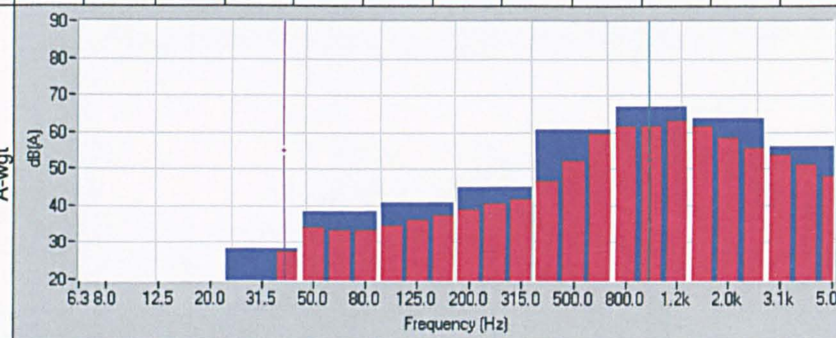
Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
3	Lin	56.67	56.24	64.16	62.52	55.55	53.62	53.17	51.68	48.26	49.75	49.41	50.29	50.81	52.94	63.24	63.04	63.77	62.82	61.54	60.07	56.16	55.02	52.24	49.47	72.7	
	A-wgt	12.56	17.8	29.31	32.68	29.05	30.83	34.14	35.72	35.3	38.91	40.65	43.76	46	49.61	61.62	62.22	63.79	63.47	62.53	61.25	57.43	56.22	53.22	50.05	70.9	1.8





Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
4	Lin	56.26	58.08	62.09	63.84	59.35	55.86	53.59	52.18	50.51	49.67	49.01	48.02	51.17	55.39	61.35	62.27	61.48	62.33	60.43	57.2	54.35	52.39	49.87	47.35	72	
	A-wgt	11.92	18.96	27.49	34.03	33.43	33.13	34.56	36.13	37.17	38.84	40.34	41.43	46.55	52.15	59.58	61.41	61.47	62.92	61.39	58.39	55.62	53.59	50.85	47.93	69.4	2.6

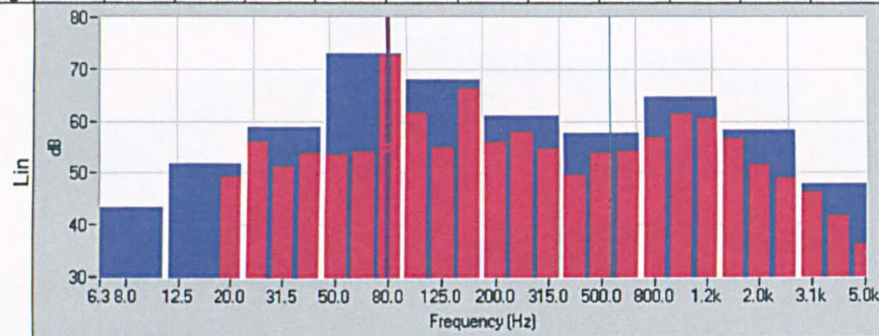


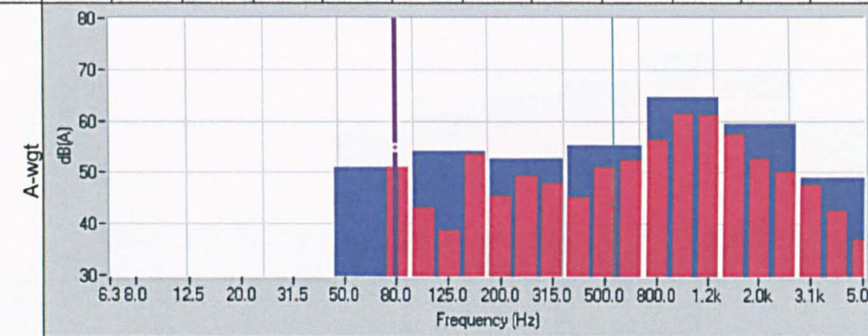


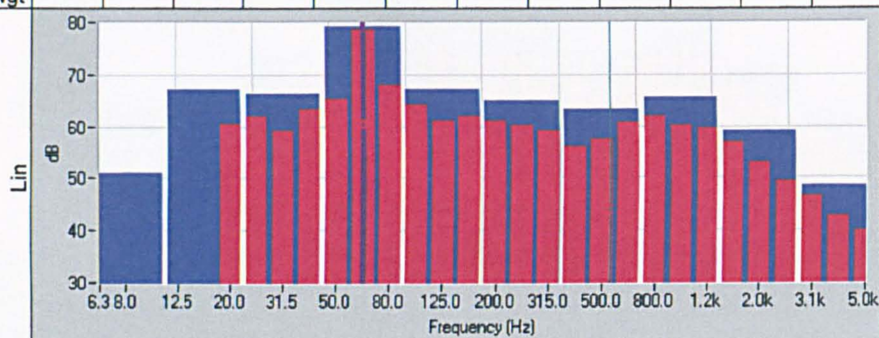
																										Avg	1.7

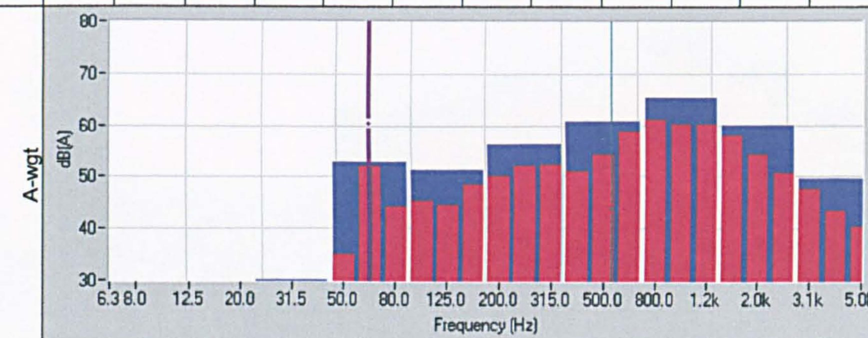
Road Traffic Noise - Third Octave Band Frequency Data (6-lane dual carriageway measured at 10m)

Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
1	Lin	55.96	51.35	53.62	53.57	54.01	72.87	61.48	54.83	66.42	55.88	57.9	54.6	49.64	53.85	53.95	56.87	61.21	60.44	56.42	51.56	48.97	46.31	41.62	36.27	75.1	
	A-wgt	11.45	13.3	19.19	23.43	27.86	51.01	43.22	38.77	53.55	45.41	49.29	47.93	44.99	50.84	52.21	56.12	61.26	60.99	57.38	52.74	50.23	47.51	42.62	36.88	66.8	8.3
2	Lin	61.73	58.91	63.24	65.28	78.62	68.02	63.98	61.14	61.89	60.9	60.29	58.99	55.96	57.46	60.62	61.88	60.19	59.52	56.94	53.01	49.37	46.41	42.55	39.8	79.7	
	A-wgt	17.69	19.81	29.3	34.95	52.15	44.23	45.33	44.54	48.3	50.15	52	52.22	51.02	54.23	58.78	61.03	60.16	60.06	57.91	54.2	50.64	47.62	43.53	40.41	68	11.7

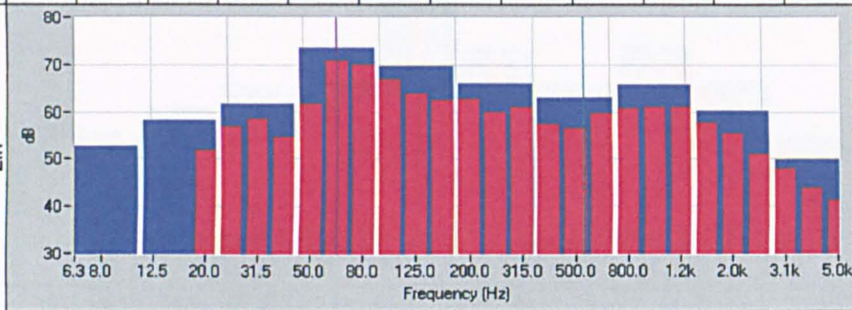


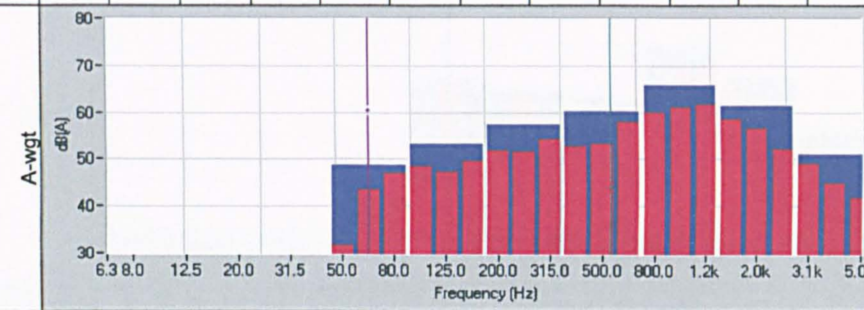




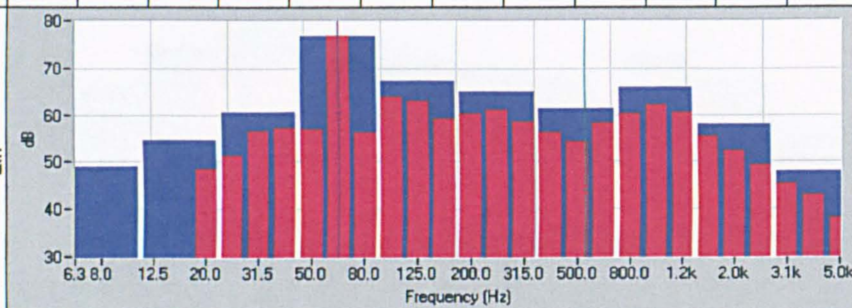


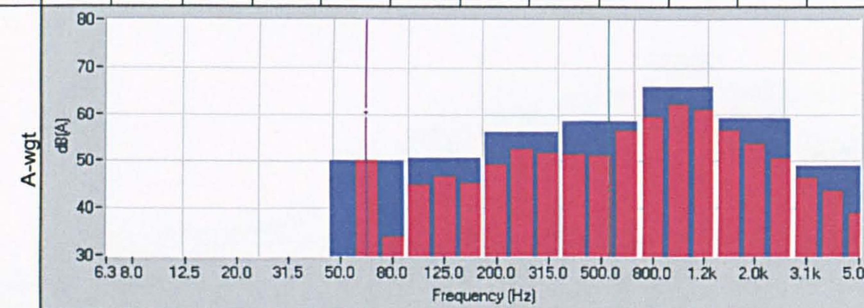
Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
3	Lin	56.7	58.59	54.5	61.61	70.86	69.82	66.83	63.89	62.47	62.58	60	60.9	57.47	56.44	59.72	60.68	60.88	61.09	57.59	55.29	50.89	47.92	43.77	41.23	76.6	
	A-wgt	12.89	20.11	20.4	31.7	43.42	46.94	48.48	47.21	49.55	51.84	51.57	54.2	52.72	53.26	57.96	59.87	60.92	61.64	58.56	56.47	52.15	49.12	44.75	41.82	68.4	8.2



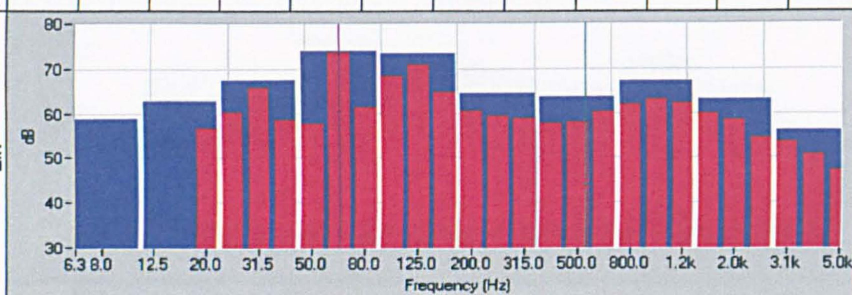


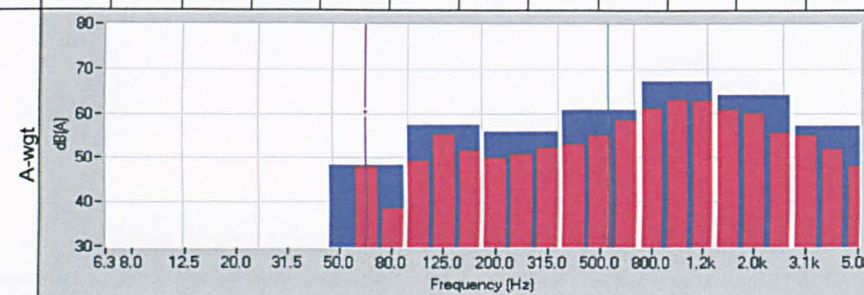
Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
4	Lin	51.21	56.48	57.16	56.87	76.62	56.23	63.72	62.99	59.09	60.28	60.95	58.47	56.39	54.2	58.35	60.15	62.03	60.41	55.54	52.43	49.35	45.39	42.75	38.18	77.9	
	A-wgt	7.13	16.85	21.92	26.46	50.02	33.83	45.19	46.84	45.45	49.27	52.51	51.78	51.61	51.14	56.52	59.37	62.08	60.94	56.51	53.62	50.61	46.59	43.74	38.8	67.7	10.2



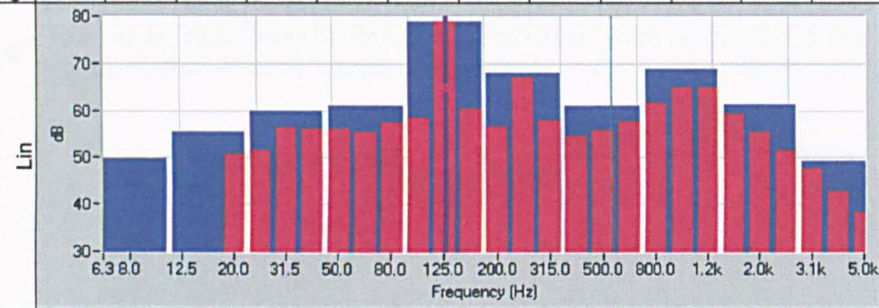


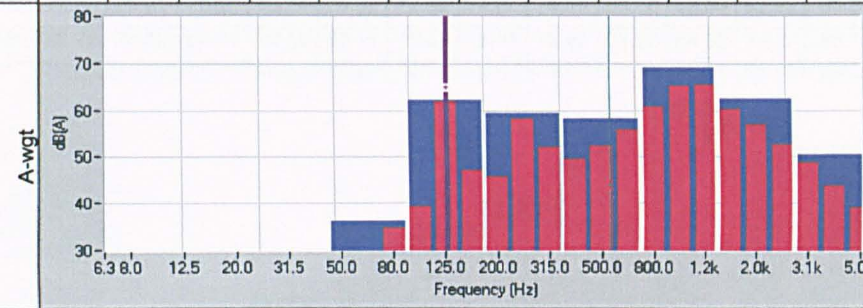
Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
5	Lin	60.19	65.82	58.51	57.76	73.49	61.23	68.28	70.7	64.59	60.5	59.22	58.88	57.61	57.83	60.27	61.87	62.92	62	59.8	58.6	54.28	53.56	50.78	47.17	78.2	
	A-wgt	15.93	26.82	23.93	27.95	47.76	38.25	49.15	55.11	51.55	49.87	50.7	52.19	52.84	54.83	58.43	61.03	62.93	62.56	60.76	59.79	55.55	54.76	51.79	47.78	70.1	8.1

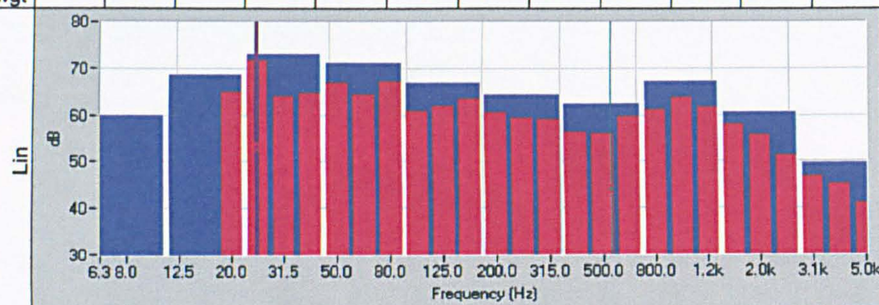


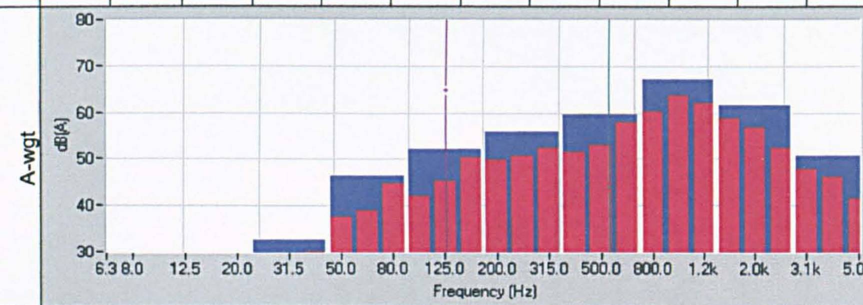


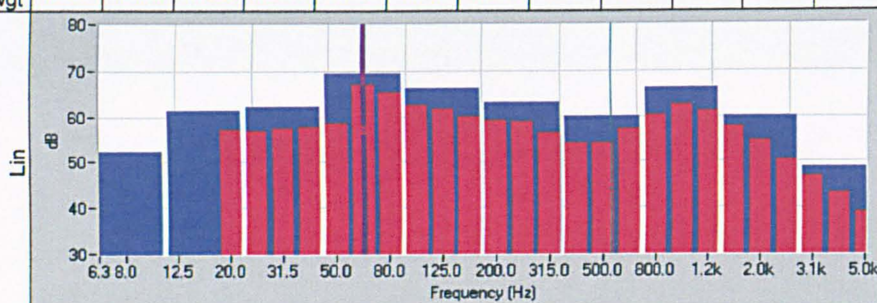
Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
6	Lin	51.41	56.22	56.02	55.99	55.42	57.29	58.43	78.86	60.33	56.44	67.24	58.07	54.6	55.59	57.6	61.63	65.04	64.98	59.32	55.56	51.45	47.51	42.83	38.34	79.4	
	A-wgt	7.71	17.11	20.97	25.98	29.68	34.62	39.32	61.92	46.95	45.64	58.12	52.07	49.61	52.36	55.79	60.87	65.11	65.48	60.27	56.74	52.72	48.72	43.82	38.96	71.1	8.3
7	Lin	71.52	64.16	64.57	66.97	64.41	67.07	60.69	61.95	63.51	60.48	59.21	58.93	56.32	56.06	59.66	60.95	63.79	61.63	57.84	55.73	51.17	46.73	45.13	40.89	77.5	
	A-wgt	25.77	25.69	30	37.55	39.03	44.7	41.93	45.44	50.35	49.93	50.55	52.35	51.42	52.91	57.84	60.12	63.76	62.21	58.79	56.91	52.43	47.92	46.11	41.48	69.1	8.4
8	Lin	56.86	57.46	57.67	58.41	66.89	65.26	62.33	61.52	59.93	59.14	58.65	56.32	53.9	53.93	57.07	60.18	62.34	60.89	57.79	54.56	50.5	46.64	43.09	38.85	73.9	
	A-wgt	12.07	18.26	23.38	28.57	40.89	42.48	43.24	45.3	46.6	48.31	50.03	49.6	49.01	50.81	55.25	59.41	62.35	61.44	58.75	55.74	51.77	47.84	44.07	39.45	68	5.9
																										Avg	8.6

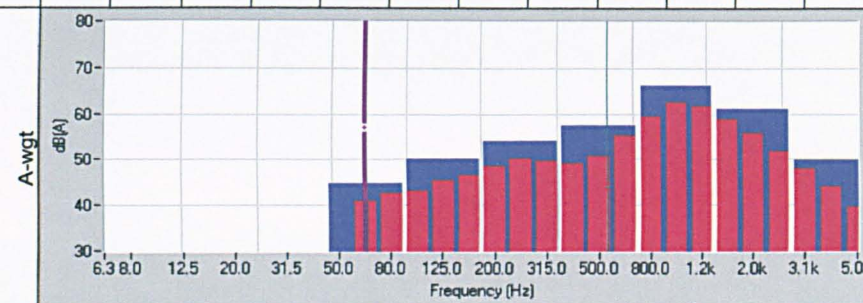








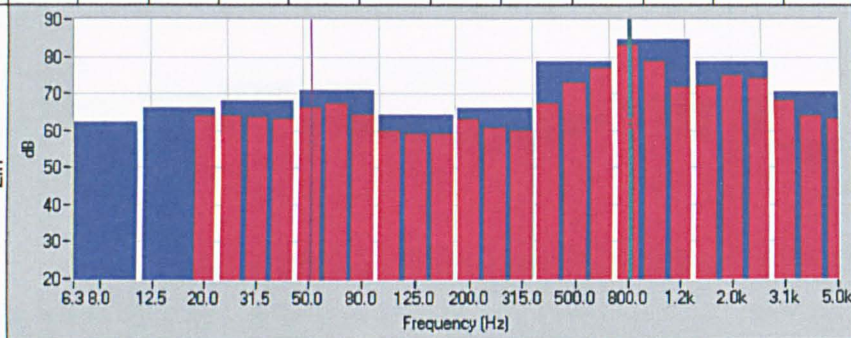




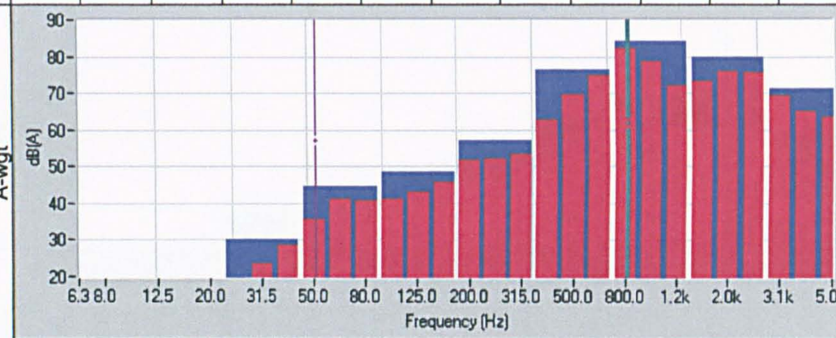
Railway Noise - Third Octave Band Frequency Data (measured at 20m)

Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
1	Lin	63.66	63.46	63.02	66.25	67.25	64.13	60.08	59.09	59.11	62.85	60.74	59.73	67.47	72.86	76.71	83	78.84	71.62	72.02	74.83	74.16	68.08	63.84	62.92	86.8	
	A-wgt	19.3	23.66	28.66	35.69	41.09	40.88	41.05	43.06	45.93	51.77	52.17	53.2	62.81	69.75	74.82	82.21	78.68	72.15	73.03	76.01	75.42	69.28	64.82	63.5	86.1	0.7

Lin

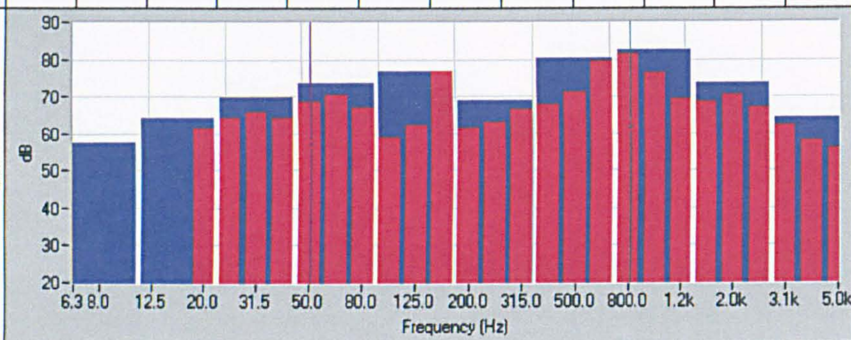


A-wgt

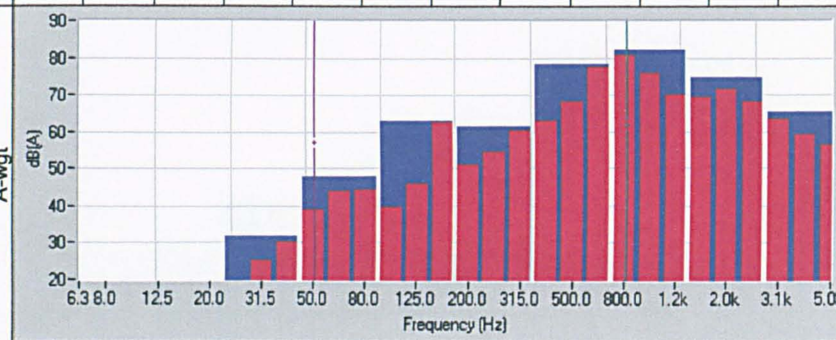


Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
2	Lin	64.13	65.63	64.22	68.68	70.31	66.85	58.7	62.1	76.66	61.46	62.86	66.58	67.79	71.15	79.47	81.31	76.18	69.47	68.36	70.37	66.89	62.19	58.09	55.85	86.1	
	A-wgt	19.49	25.17	30.29	38.91	43.81	44.13	39.53	45.92	62.72	50.93	54.38	60.26	63.07	68	77.66	80.45	76.06	69.98	69.37	71.57	68.15	63.4	59.08	56.44	84.2	1.9

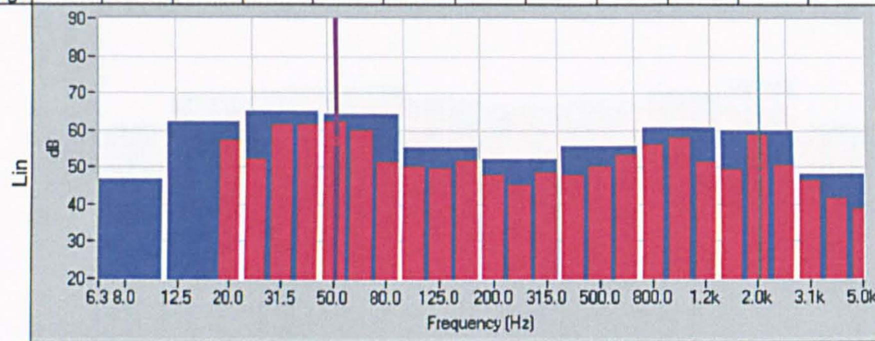
Lin

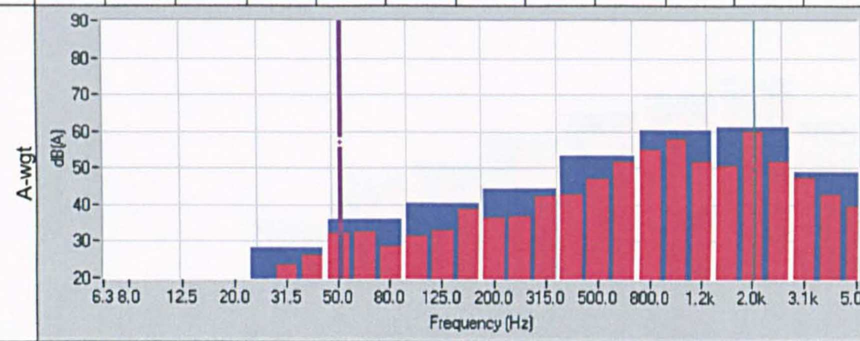


A-wgt

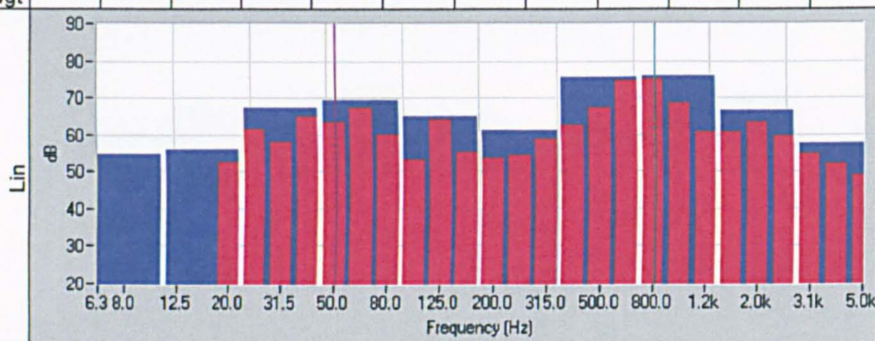


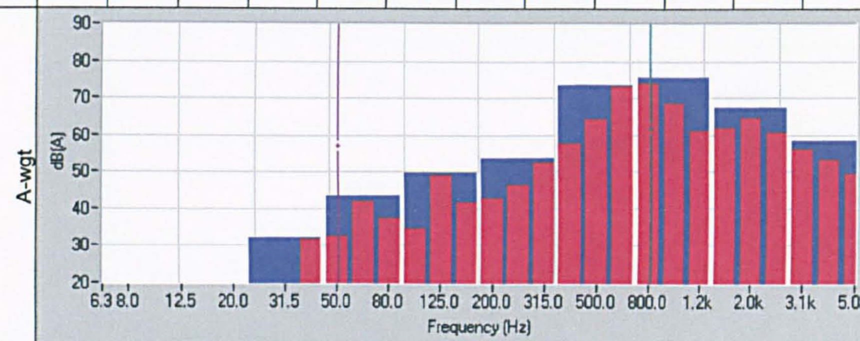
Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
3	Lin	52.07	61.61	61.62	62.18	59.7	51.33	50.01	49.66	51.66	47.6	45.22	48.52	47.62	50.08	53.26	55.86	57.79	51.16	49.41	58.71	50.36	46.2	41.54	38.85	70.2	
	A-wgt	8.07	23.47	26.43	32.03	32.33	28.7	31.15	33.02	38.58	36.47	36.82	42.1	42.76	46.8	51.54	54.94	57.8	51.71	50.4	59.91	51.62	47.41	42.53	39.44	64.2	6



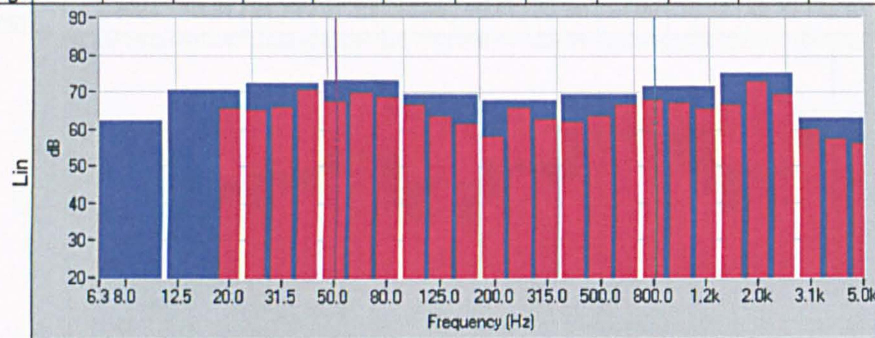


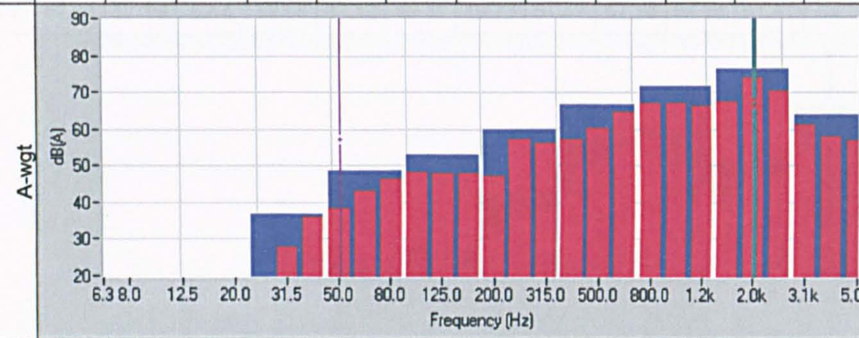
4	Lin	61.6	57.89	65.13	63.24	67.25	59.8	53.36	64.1	55.25	53.67	54.6	58.77	62.51	67.35	74.77	74.95	68.66	60.56	60.8	63.47	59.54	54.86	52.22	48.82	80	
	A-wgt	17.21	19.2	31.89	32.71	41.82	37.08	34.43	48.88	41.6	42.85	46.03	52.45	57.71	64.36	73.01	74.1	68.59	61.09	61.78	64.67	60.8	56.06	53.21	49.45	78.1	1.9



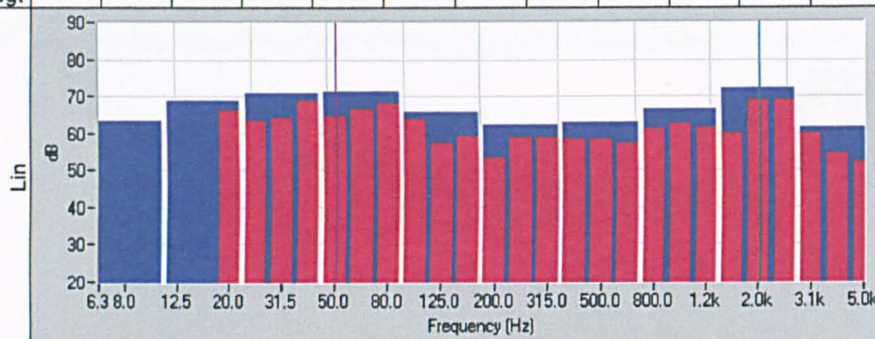


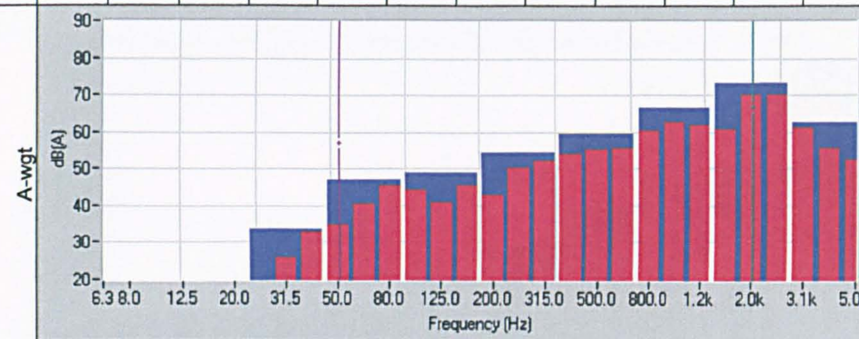
Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
5	Lin	64.98	65.72	70.34	67.33	69.6	68.37	66.61	63.56	61.57	57.87	65.61	62.69	62.02	63.33	66.39	67.89	67.01	65.39	66.46	72.86	69.33	60.03	57.14	56.14	80.9	
	A-wgt	18.96	27.74	36.08	38.18	42.88	46.3	48.16	47.79	47.8	47.12	57.17	56.05	57.16	60.29	64.6	67.04	66.97	65.96	67.42	74.07	70.59	61.23	58.13	56.75	78.1	2.8





Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
6	Lin	63.25	64.17	68.71	64.58	66.43	68	63.69	57.1	58.92	53.34	58.58	58.59	58.46	58.39	57.33	61.09	62.57	61.38	59.73	68.99	68.73	59.9	54.48	52.02	78.1	
	A-wgt	16.72	25.85	32.92	34.75	40.47	45.32	44.23	40.82	45.6	42.58	50.21	51.98	53.87	55.13	55.53	60.27	62.6	61.88	60.73	70.22	69.99	61.1	55.46	52.63	74.7	3.4



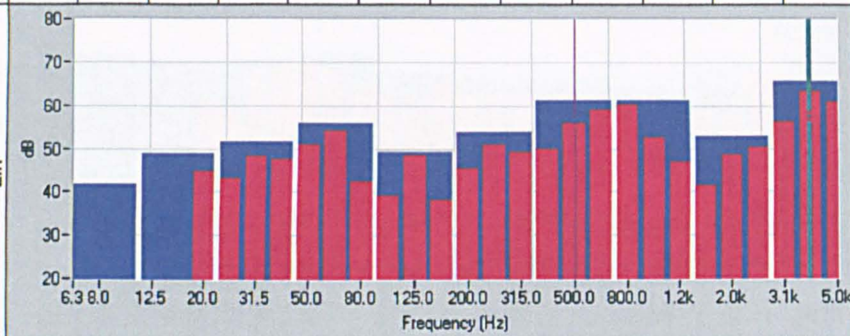


																										Avg	2.8

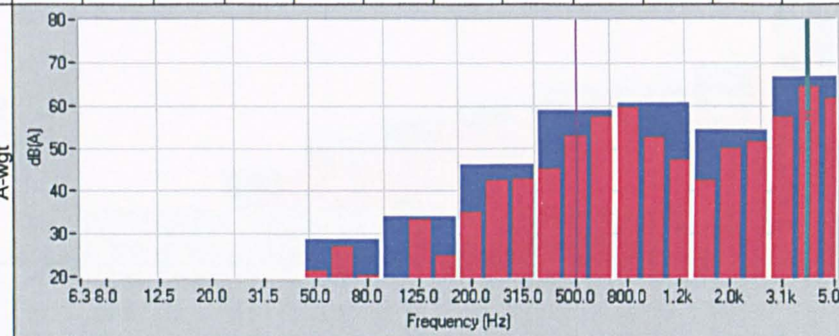
Birdsong - Third Octave Band Frequency Data (measured at <10m)

Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
1	Lin	43.14	48.31	47.35	50.74	54.14	42.53	39.05	48.34	38.22	45.54	50.76	49	49.98	55.9	59.03	60.37	52.68	46.68	41.36	48.5	50.31	56.06	63.27	60.75	68.7	
	A-wgt	-1.5	8.23	13.81	21.24	27.13	20.45	19.81	33.36	24.98	35.12	42.52	42.91	45.2	52.84	57.19	59.4	52.55	47.19	42.31	49.73	51.57	57.26	64.24	61.41	68.3	0.4

Lin

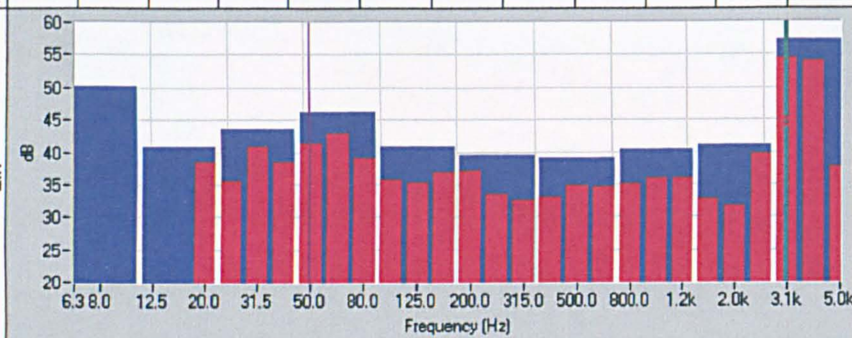


A-wgt

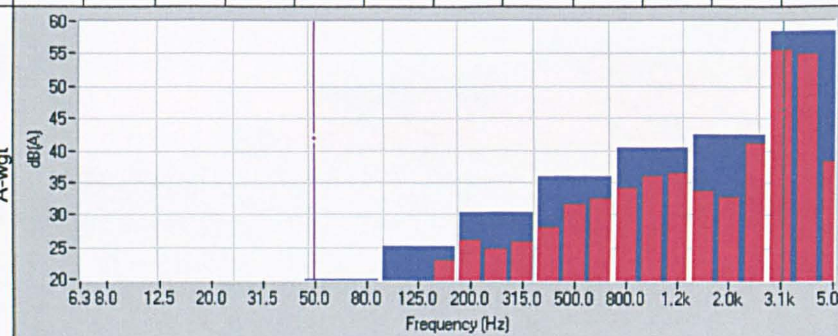


Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
2	Lin	35.32	40.8	38.4	41.3	42.84	38.93	35.61	35.13	36.79	36.99	33.42	32.61	32.91	34.82	34.55	34.88	35.94	35.82	32.77	31.62	39.75	54.49	53.88	37.73	58.8	
	A-wgt	-8.83	1.72	4.06	11.46	17.18	15.55	16.66	19.14	22.99	25.98	24.76	25.8	28.06	31.63	32.62	34.05	35.93	36.37	33.73	32.82	41.01	55.63	54.95	38.39	58.6	0.2

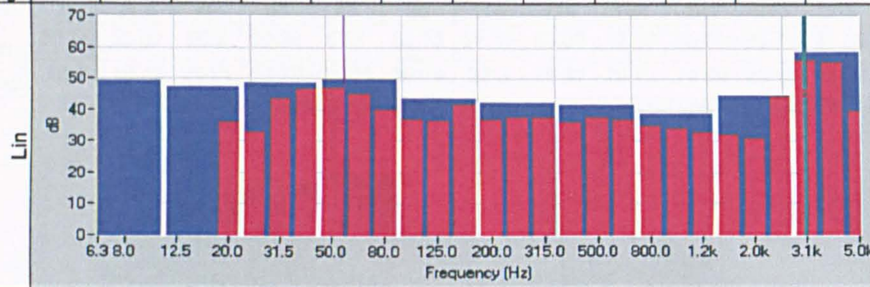
Lin

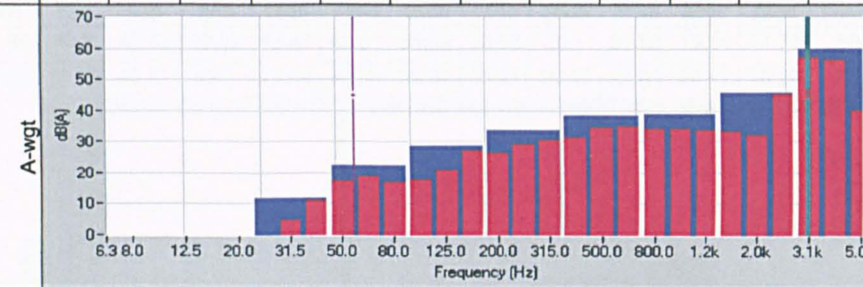


A-wgt

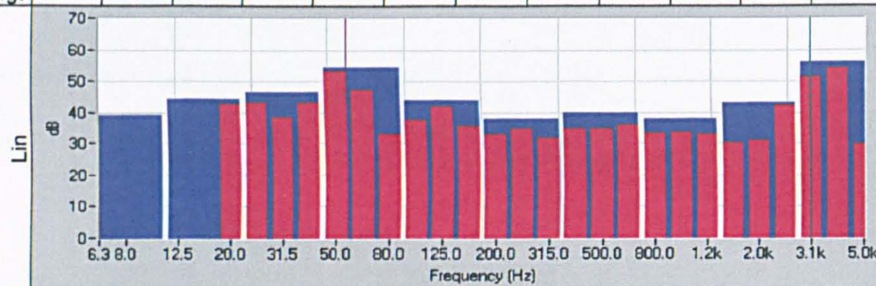


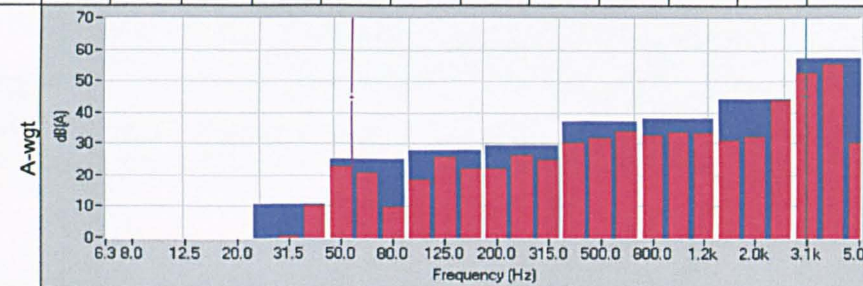
Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
3	Lin	32.9	43.58	46.71	46.87	45.07	39.96	36.93	36.23	41.27	36.86	37.71	37.48	35.96	37.49	36.77	34.94	34.1	33.02	32.25	31.04	44.11	56.03	55.11	39.35	60.5	
	A-wgt	-12.59	4.82	10.89	17.03	18.62	16.68	17.64	20.67	27.18	26.11	29.12	30.57	31.14	34.41	34.77	34.05	34.09	33.59	33.21	32.24	45.37	57.18	56.18	39.98	60	0.5



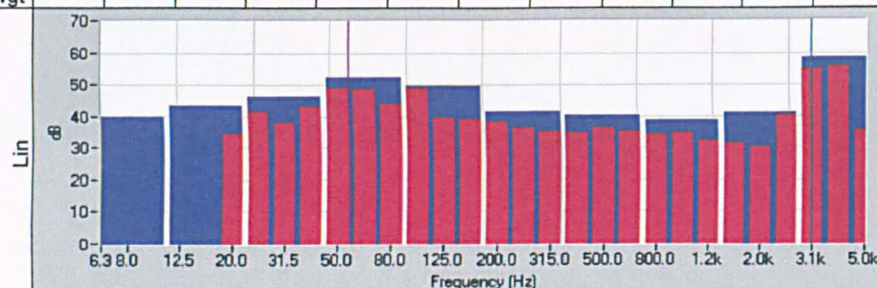


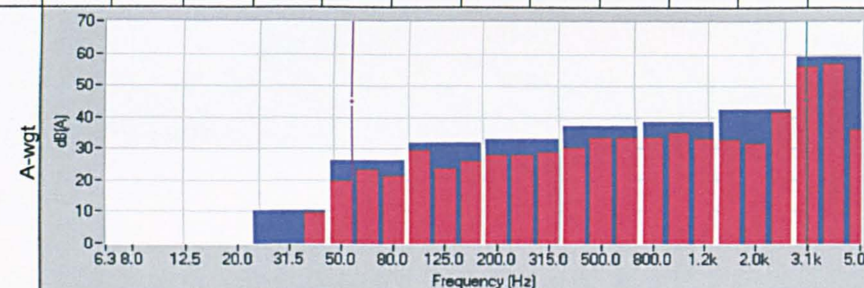
Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
4	Lin	42.85	38.47	42.96	53.22	47.29	32.76	37.48	41.67	35.72	32.78	34.77	31.52	34.88	34.93	35.82	33.25	33.51	32.68	30	30.72	42.36	51.07	54.08	29.63	59	
	A-wgt	-3.81	0.42	10.09	22.54	20.71	9.76	18.45	25.85	21.96	21.71	26.14	24.71	30.1	31.7	34.02	32.37	33.49	33.22	30.97	31.92	43.62	52.25	55.1	30.26	57.3	1.7





Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
5	Lin	41.45	38.09	43.05	49.03	48.67	43.71	48.79	39.35	39.05	38.42	36.31	35.23	34.93	36.56	35.18	33.94	34.86	32.18	31.44	30.15	40.3	54.67	55.53	35.62	60.2	
	A-wgt	-3.09	-1.25	9.45	19.45	22.96	21.26	29.39	23.34	25.75	27.61	27.61	28.53	30.2	33.36	33.22	33.19	34.84	32.76	32.42	31.34	41.57	55.79	56.6	36.12	59.4	0.8





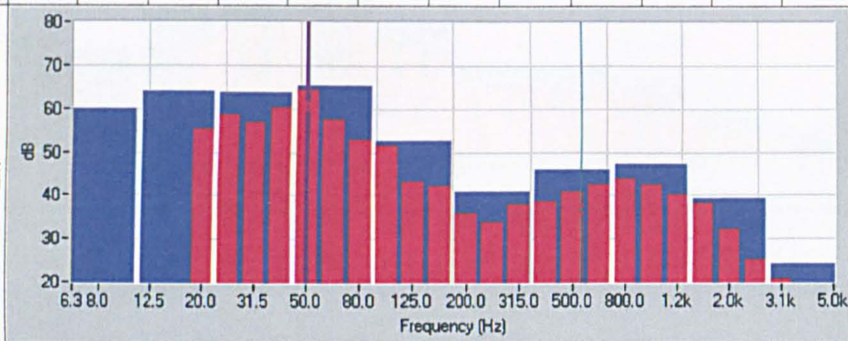
																								Avg	0.7

Background Noise Levels - Third Octave Band Frequency Data

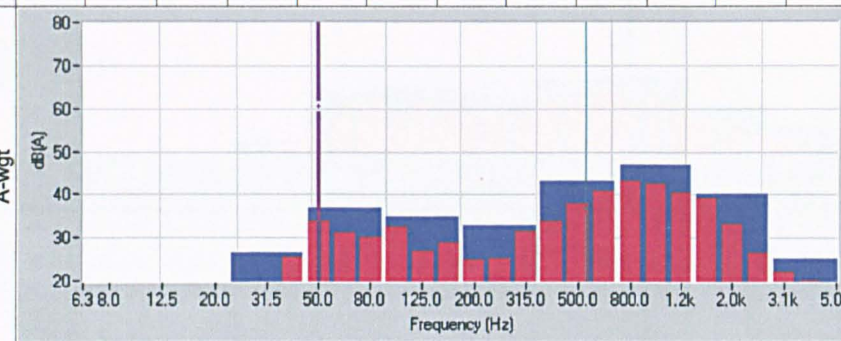
Samples: 1-3, rural day; 4-5, urban day; 6-7, urban night

Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
1	Lin	58.38	56.89	60.2	64.28	57.4	52.73	51.43	43.03	42.29	35.71	33.79	37.69	38.44	40.9	42.43	43.89	42.47	40.01	38.09	32.03	25.1	20.83	19.14	17.71	69.7	
	A-wgt	13.7	18.42	25.21	33.89	31.18	30.19	32.3	26.82	28.72	24.59	25.15	31.23	33.63	37.76	40.71	43.1	42.44	40.55	39.02	33.21	26.36	22.03	20.11	18.29	49.6	20.1

Lin

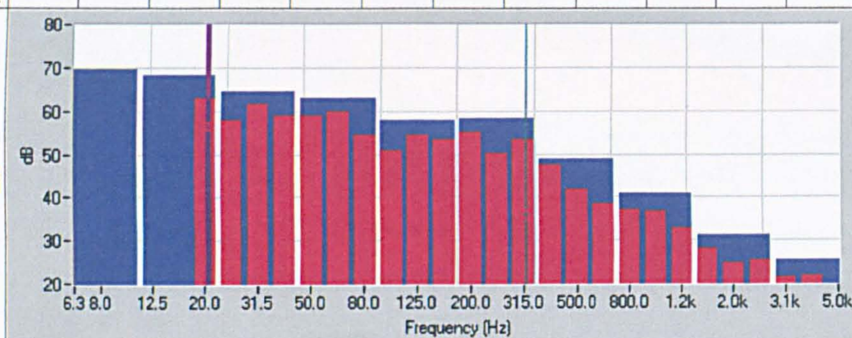


A-wgt

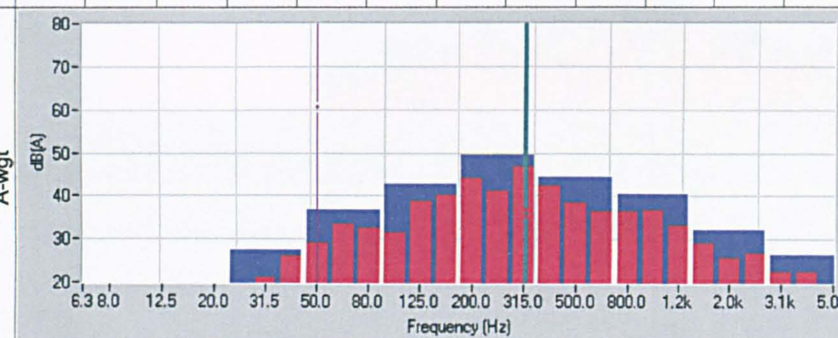


Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
2	Lin	58.02	61.47	58.88	58.97	59.76	54.53	50.89	54.68	53.38	55.21	50.16	53.55	47.58	41.64	38.32	37.05	36.69	32.64	28.01	24.59	25.38	21.24	21.55	18.88	73.5	
	A-wgt	13.02	21.16	25.96	29.03	33.57	32.33	31.31	38.9	39.99	44.13	41.22	46.76	42.33	38.44	36.37	36.26	36.64	33.19	28.95	25.78	26.65	22.43	22.5	19.45	51.8	21.7

Lin

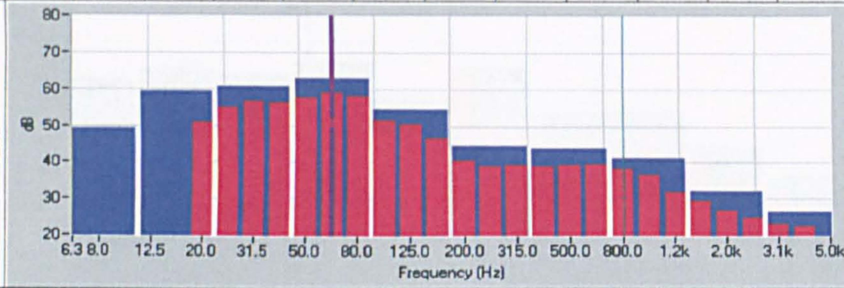


A-wgt

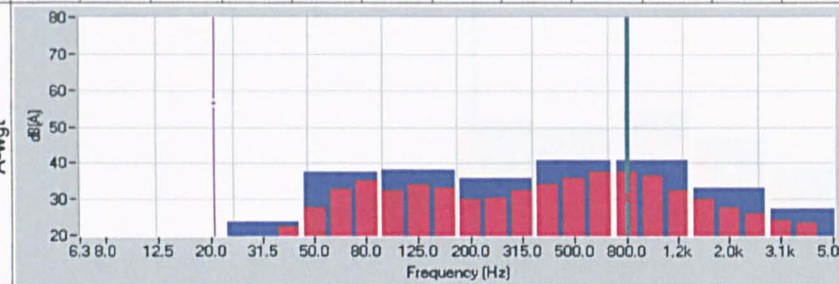


Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
3	Lin	54.91	56.39	56.18	57.39	58.78	57.88	51.38	50.41	46.35	40.56	38.92	38.97	38.79	39.08	39.44	38.25	36.56	31.84	29.24	26.63	24.72	22.86	22.36	19.12	66.4	
	A-wgt	9.53	16.81	22.25	27.54	32.9	35.01	32.24	34.09	33.05	29.94	30.23	32.28	33.92	35.8	37.59	37.38	36.52	32.37	30.21	27.82	25.99	24.05	23.34	19.73	46.3	20.1

Lin

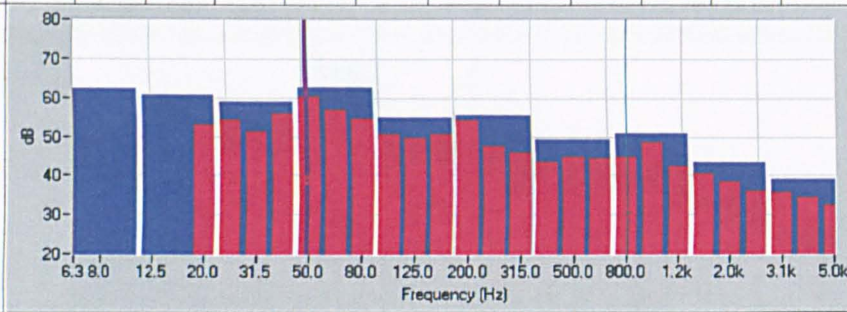


A-wgt

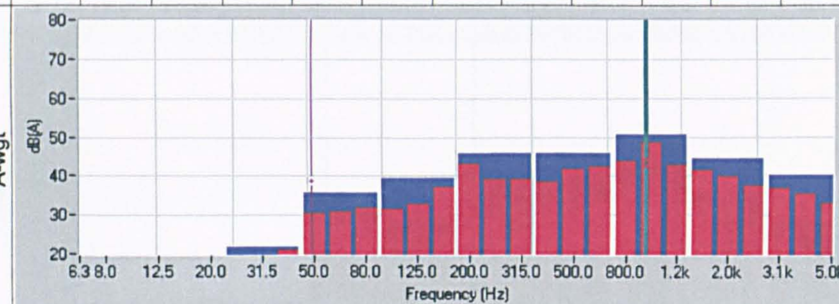


Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
4	Lin	54.22	51.31	55.8	60.1	56.94	54.65	50.62	49.34	50.52	54.26	47.54	45.76	43.4	44.78	44.44	44.68	48.56	42.33	40.42	38.51	36.23	35.6	34.39	32.34	68	
	A-wgt	8.62	12.76	20.92	30.51	30.89	31.6	31.54	32.73	37.24	43.12	39.13	39.15	38.47	41.62	42.45	43.84	48.6	42.9	41.39	39.7	37.5	36.8	35.35	32.94	53.9	14.1

Lin

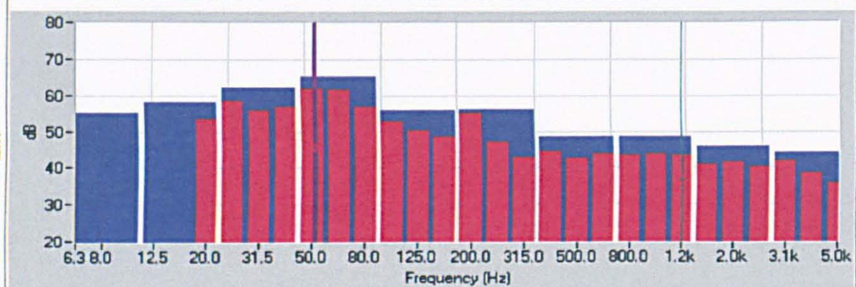


A-wgt

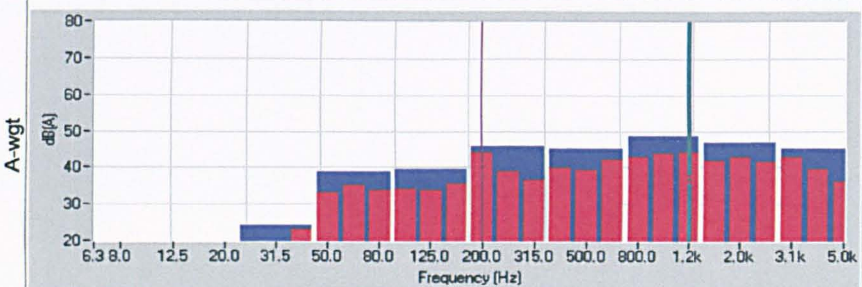


Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
5	Lin	58.63	55.91	56.91	61.74	61.55	56.79	52.99	50.06	48.65	55.28	47.21	42.79	44.56	42.55	43.83	43.43	43.87	43.49	40.91	41.62	40.14	41.71	38.38	35.63	68.4	
	A-wgt	13.08	15.59	22.86	32.92	35.16	33.64	34.17	33.84	35.51	44.13	38.67	36.34	39.85	39.21	41.97	42.68	43.86	44.08	41.89	42.8	41.41	42.91	39.36	36.25	53.7	14.7

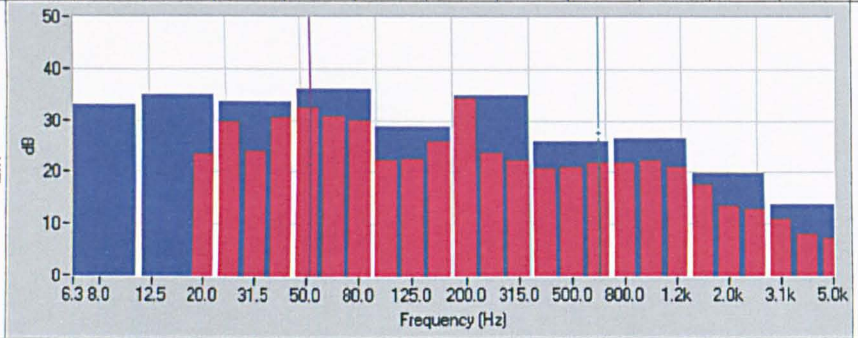
Lin

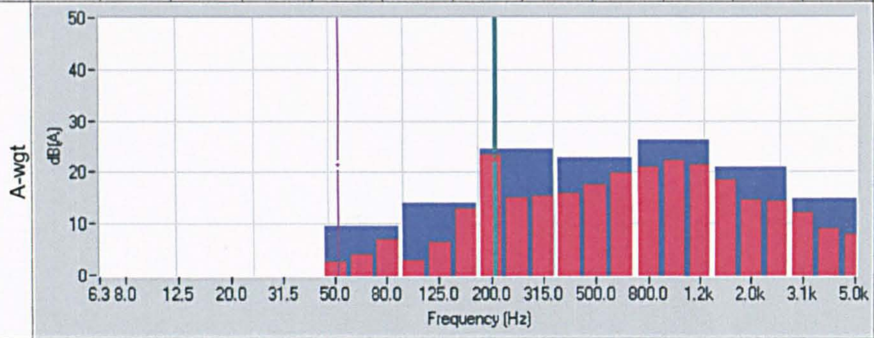


A-wgt

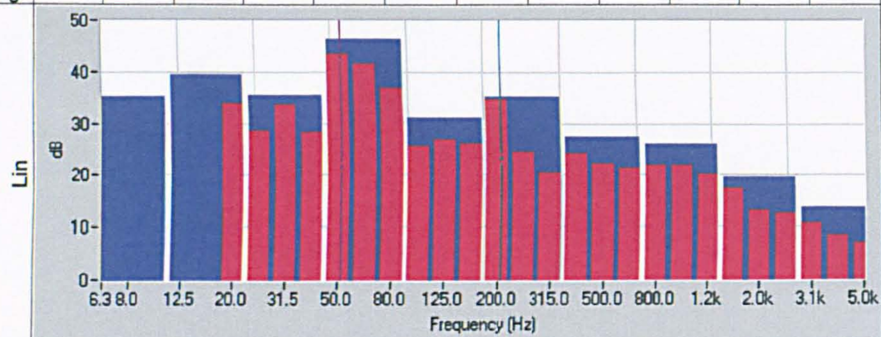


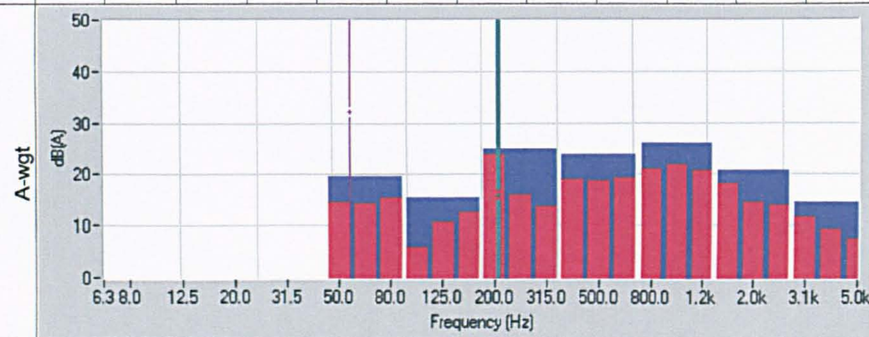
Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
6	Lin	29.61	24.02	30.47	32.37	30.73	29.89	22.24	22.5	25.94	34.24	23.82	22.23	20.8	21.01	21.76	21.7	22.27	20.86	17.48	13.48	12.95	10.82	8.04	7.2	42.1	
	A-wgt	-16.03	-15.54	-4.74	2.39	3.94	6.9	2.93	6.42	12.75	23.37	14.98	15.39	15.99	17.71	19.81	20.84	22.27	21.41	18.45	14.66	14.22	12.01	9.02	7.77	30.4	11.7





Sample	Hz	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Total	Diff
7	Lin	28.41	33.42	28.11	43.7	41.7	36.98	25.55	26.89	25.98	34.65	24.41	20.38	23.92	22.01	21.28	21.73	21.88	20.24	17.23	13.25	12.71	10.51	8.33	6.95	48.1	
	A-wgt	-17.73	-5.25	-4.83	14.52	14.17	15.36	5.98	10.74	12.61	23.78	15.89	13.58	19.01	18.72	19.37	20.94	21.86	20.8	18.18	14.44	13.97	11.7	9.3	7.52	30.8	17.3





																										Avg	17.1